IMPLICATION OF INFORMATION DISRUPTION TO SUPPLY CHAIN IMPROVEMENT STRATEGY DECISION - AN ENTROPY PERSPECTIVE

By

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DEDICATION

To my wife, Esther Preeti, and son, Samuel Boluwatife Tanay

To my Parents, Chief and Chief Mrs Durowoju

To my father-in-law, Rev. Irwin Lall and late Mother-in-law, Mrs Vijaya Lall

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ABSTRACT

Implication of Information Disruption to Supply Chain Improvement Strategy Decision - An Entropy Perspective

Impact studies relating to information security breach are few and somewhat understudied. This study was carried out with a view to create a better understanding of how information security breaches affect the performance of the supply chain and the role certain strategic factors (also called complexity drivers) play in either mitigating the level of impact or exacerbating it. Three categories of strategic factors are considered: ordering policy; supply chain structure; and information sharing/integration, and each category has 3 or more alternatives used for comparison. Using discrete event simulation (DES), the study found that these strategic factors help improve supply chain performance in the face of supply chain disruption as long as the right combination of alternatives are used. At another level, this thesis exposes the counter-intuitiveness of combining certain strategic factors.

Beyond estimating the cost impact of information security breach, this study found that impact uncertainty has been overlooked in previous studies and this could be misleading and ultimately become the bane of existence for organisations that do not factor in the consequence of uncertainty in their impact cost estimation. This may result in treating a serious security threat as benign. Using the concept of entropy theory the study developed a methodology that helps measure the uncertainty associated with impact cost estimation. In addition a decision framework was developed, which includes an uncertainty cost implication component that helps make better strategic decisions.

This study advances the field of impact assessment in that it proposes a more inclusive approach to impact assessment and helps in understanding where supply chain priorities lay both under normal and disruption circumstances. This understanding is key to making sustainable improvements to the supply chain either with a short term view or from a long term perspective.

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Chapter 1 INTRODUCTION

1.1BACKGROUND

Traditionally, Supply Chain Management (SCM) focused around the manufacturer and their immediate suppliers. But in today's world, SCM focuses on the optimization of all movement of goods and/or services and the flow of information, starting with the suppliers' supplier all the way through to the customers' customer (Plenert, 2002). In other words, firms have seen the need to manage the physical flows and the information flows up and down the supply stream in a coordinated manner. Management of these flows are increasingly becoming more challenging as there is currently a marked increase in the geographical dispersion of manufacturing sites, suppliers, warehouses and customers in today's supply networks (Colotla et al., 2003). However, Information Technology (IT) has been effective in improving the efficiency of inter-organizational operations by mitigating uncertainties inherent in collaborative networks via efficient transmission of information. IT has been used extensively by supply networks to enhance the efficiency and effectiveness of supply operations. Beyond that, it has been used as a vehicle for both internal and external integration. For most organizations IT is core to their competitive advantage.

According to Wiengarten et al (2010) information quality plays a pivotal role in the success of collaborative practices, and this is due to quality factors such as timeliness, accuracy, relevance and added value of the shared information. It is safe to say that most organizations are now extending the way IT is being utilized to improve their competitiveness in this highly competitive global market. For example the concept of cloud computing is a somewhat recent development in the way IT is being exploited where hardware or software resources, or a combination of both, are accessed anywhere in the world by an organization or an individual via the internet (Amir, 2009, Smith, 2009, Armbrust et al., 2010). These resources are shared amongst many users, abstracted, available on demand, scalable, and configurable (Marston et al. , 2011). Some have even extended the concept to manufacturing where product design, manufacturing, testing, management, and all other stages of a product life cycle are encapsulated into cloud services and managed centrally (Xu, 2012) similar in principle to (but not the same as) distributed manufacturing described in Dekkers and Bennett (2009). Essentially the idea is to pay for what you

use as opposed to renting where you pay for the specified period irrespective of use (Subashini and Kavitha, 2011), which can be quite expensive. These growing advantages of leveraging processes using IT and the fact that IT cost is becoming more and more inexpensive have led to the increasing level of collaboration found in many networks.

There is an increase in the level of connectivity and interdependency (referred to as complexity) found in the network as businesses come together in the spirit of collaboration being geographically distant from one another. These complexities affect the dynamics of the network and thus require an appropriate network management approach. It is perceptible that as complexity increases so does the level of uncertainty enveloping the business or supply chain. A compromise in the operations of one member could affect other interconnected members of the network, the extent to which depends on how reliant their operations are on the compromised company (Craighead et al., 2007). It is therefore apparent that strategies should change to accommodate the increased or increasing complexity present in the supply chain. Consequently there should be a pro rata increase in the level of information required to monitor and control the operations of the network.

Nowadays it is difficult to separate information from operation as the absence of information results in the poor performance of supply operations. Managing supply operations effectively requires efficient management and use of information. One cannot be managed with total disregard to the other, it will only spell disaster. The fusion of both is crucial to business survival and serves as the foundation for competitive advantage. This study is positioned to examine an aspect of supply chain management which is information management by looking at the disruption in the flow of information and how this affects supply chain management practices. It will be interesting to know which areas of operation are most vulnerable.

1.2 NEED FOR INFORMATION SECURITY MANAGEMENT

As information is shared with the aid of Information Technologies (IT) and Information Systems (IS), practitioners, therefore, are expected to increase their effort in protecting their systems to reduce their vulnerability to system failure. However, security controls appear to be lagging behind the use of new technology (Baker et al., 2010, Potter and Beard, 2012). This is due in part to the fact that the

number of occurrence of these incidents is quite small and very unpredictable, therefore most practitioners are not motivated to plan against them as planning incurs a huge cost. Besides this, most organizations are not even prepared to restore their services after disruption from information security breach[1] and are unable to manage other consequential impacts on the organization. It is therefore necessary for each organization to assess the impact of security incidences on business operations, regardless of whether they have never experienced it before, and how this affects other businesses linked to it. This assessment should reveal 'where?', 'what?' and 'how?' business is affected and this in turn would provide the necessary incentive that will encourage managers to proactively plan for any future occurrence. Pre-empting disruption and planning for and against it has been shown by Mitroff and Alpaslan (2003) to be beneficial to firms as proactive businesses existed for an average of sixteen years more than their reactive counterparts. Unfortunately businesses are still not taking this issue as seriously as they should. According to Mitroff and Alpaslan (2003) and Altay and Ramirez (2010), 95 percent of Fortune 500 companies are unlikely to be able to manage a disruption that the company has not experienced before because they are unprepared. There is therefore the need to profile different information security breach types (also called threats[2]) in order to understand the level of impact each has on an organization or supply chain as no two threats are exactly the same and they differ in the magnitude of impact each has on a business and supply chain.

As threats to information security take various forms, their incidence could reduce the quality of information or even prevent accessibility to information. These incidences may result in delayed transmission of information which might reduce the relevance or value of the information, or altogether jeopardize the accuracy of the shared information. Depending on the form of threat, they can cause systems to crash preventing suppliers and other Supply chain members from having access to the service, hence disrupting the flow of transactions leading to loss of money amongst

[1] The incidence of an information security threat compromising the integrity, confidentiality or availability of information needed for daily operations

[2] An event or action that can potentially inflict harm or damage to the functioning of an IT system

other intangible yet crucial losses. A classic example is the 2011 breach incidence in Sony's PlayStation Network (PSN) which resulted in unavailability of service for weeks and cost the business billions of dollars (Osawa, 2011).

1.3 NEED FOR APPROPRIATE SUPPLY CHAIN MANAGEMENT STRATEGY

Organizations now understand the value of information and the need to protect their information from outsiders with malicious intent or from competitors to maintain the competitive advantage they have by leveraging such information. By examining the impact of each threat, one can lay a foundation upon which appropriate supply chain decisions are made. It is important to understand what level of integration (or information sharing) in the supply chain is appropriate considering the impact these threats have and how it affects performance of the entire network. Equally important is the way the entire network can be reconfigured to increase its resilience to threat impact outside of information security management efforts. For example which ordering policy would reduce the impact of information security breach on the supply chain performance more and how does impact at one tier in the supply chain affect the entire network? Also how are the different supply structures affected by these threat impacts. Beyond this, management should concern themselves with the areas of operation that requires the most attention depending on their vulnerability. Combining the answers to these questions would help create a better understanding of the dynamics of the supply chain and the interaction between information management and operations management. This would inform an appropriate strategy designed to cater for the needs of specific collaborative networks. This study stems from the need to develop concepts suitably adapted to supply chain management which is different from those intended for individual organizations. Understanding some of the dynamics mentioned earlier provides valuable insight and is a positive step in the right direction.

1.4 PROBLEM STATEMENT

Threats to the security of an IT system are becoming increasingly sophisticated and may result into loss of integrity, disruption of service and/or loss of confidentiality. Therefore the security risk of any Information System (IS) should be assessed and the appropriate countermeasures at the right level should be implemented. There are

many studies on the financial impact of threats to an organization, and a few have studied the distribution of risk to supply chain members. However there is yet to be found, a study in literature that has investigated the impact of information security breach on the performance of the supply chain at both operational (supply chain agent level) and strategic level (supply chain as a whole). Studies which have investigated the impact of security breaches have been largely qualitative and confined to individual organizations. These studies are quite subjective and lack consistency. There is need for an objective assessment which a quantitative study offers. This study will fill this important gap by conducting a quantitative assessment of the impact of information security breach and provide knowledge on how the incidence of these threats affects the operations of the supply chain. To prevent any obfuscation of terms, some of the key terms used in this study are defined in Table 1.1.

Term	Definition
Threat	An information security related event or action that can potentially inflict harm or damage to the functioning of an IT system
Breach	The incidence of a threat or the onset of an attack.
Information Security Breach	The incidence of an IT related threat compromising the integrity, confidentiality or availability of information needed for daily operations
Risk	The chance of a threat occurring (in this case Information security breach) having either a negative or positive impact on a firm or supply chain
Uncertainty	Refers to the unpredictability of the what future impact would be whether positive or negative or what the extent of negative impact will be
Supply Structure	The configuration of the supply chain that indicates the number of agents in each tier of the supply chain
Entropy	A measure of the amount of uncertainty associated with predicting future impact of a specific breach under varying supply context.
Ordering pattern	This is defined as the combination of the average effective order quantity and the frequency of placing an order

Table 1.1 Definition of key terms

In assessing risk, in this case threats to information security, the impact of the incidence of such threat should first be estimated. It is apparent from literature that this estimation has not been sufficiently covered as it is not understood how an attack in one business will affect other aspects of the supply chain. This is called the

reverberating effect. Putting this in a supply chain context, it is not yet evidenced whether this will have a ripple effect (similar in principle to the bull-whip effect where there is significant increase in impact) or a trickle-down effect (i.e. where there is not a significant increase in impact) on members as one goes upstream the supply chain. Several questions arise from past studies which beg for answers. For example how does security breach affect each member of the supply chain, and what effect does it have on the entire chain? What effect does the structure of the supply chain have on how security breach impacts supply chain performance? What effect does the level of integration of the supply chain have on how security breach impacts supply chain performance? How does the ordering decision mitigate or exacerbates the impact that information security breach has on supply chain performance? The formal research questions of this thesis will be formulated in the next section.

1.5 OBJECTIVE AND SCOPE OF RESEARCH

1.5.1 Strategic Factors Considered in the Study

Four structures are considered namely: serial, wholesaler type (WH), manufacturer type (MF) and network type (NT). These are properly defined in the methodology section. The WH and MF structures are considered to be structural reconfiguration strategies which entail a unification and simplification of two separate serial structures where there is only one agent in the wholesaler and manufacturer tiers respectively while the NT structure is considered a risk pooling strategy where each tier aggregates demand from downstream and shares it equally amongst themselves.

To study the effect of integration, information sharing (also termed information integration) is conceptualised in this study as an upstream agent privy to the demand and other related inventory information of a downstream agent. Examples of the information being shared are inventory position, safety factor, lead time, ordering cost, backlog cost and holding cost. Four levels of information integration are considered: no integration (NI); integration between the retailer and wholesaler (RW); integration between the wholesaler and manufacturer only (WM); and integration between all three agents (RWM). RW and WM are partial forms of information integration existing between different agents.

Three ordering policies are examined based on the ‘how much to order’ decision. The first ordering policy considered is the parameter based ordering system where

the decision on how much is being ordered to the upstream agent is determined by the difference or addition of two or more decision parameters. The second ordering policy is called the batch or fixed ordering system where the order quantity has a somewhat fixed value. The third one considered in this study is the combined batch-and-parameter based ordering system where the order size is determined by a combination of fixed order quantity and a parameter based order quantity. These are fully explained in the literature review (Chapter 2) and methodology (Chapter 3).

1.5.2 Research Questions

The combination of the supply structure or configuration, the ordering policy and the level of information sharing may be different for various supply chains and this brings about varying levels of complexity. Complexity is mostly construed to mean the configuration of physical asset, material flow and operational characteristic or property of the supply chain which makes operations difficult to manage effectively and efficiently (Serdarasan (2013) Wilding (1998)). In summary, it is the aim of this research to provide insight on how these complexities affect the impact that various information security breaches have on supply chain performance. To do this this study is divided into three parts, Study 1, 2 and 3.

1.5.2.1 Study 1

The first study examines the influence of the interaction between these strategic factors under normal circumstances (i.e. in a non-information security breach scenario). Effectively the main question here is:

Question 1: *How do these strategic factors interact and what influence do these interactions have on supply chain performance?*

Studying the effect of these three strategic factors in a single study has been missing in literature and this study aims to fill that gap. Therefore the study examines the interaction between these three factors and the effect of this interaction on supply chain performance, which has not been studied extensively in the past. This knowledge is important to build a better holistic understanding of the dynamics of supply chain interactions. More to the point is that this study also serves as a reference point for the next study which is understanding the impact of information security breach and the role of these strategic factors in either mitigating or exacerbating this impact.

1.5.2.2 Study 2

The second study builds on the first study to determine what the impact of information security breach is on supply chain performance. However, while it is important to understand the cost impact of these breaches, it is more so imperative to establish which aspects of operation or areas in the supply chain are most vulnerable. This will particularly help the supply chain prioritize 'what?' and 'where?' along the supply chain require immediate protection and what appropriate mitigation solution should be adopted on the long run. This way, the supply chain can effectively and efficiently plan its operations, optimally prepared for any eventualities. To build this understanding, the following questions are proposed and answered:

Question 2: *Does the impact of information security breach increases or decreases as one goes upstream?*

Question 3: *What is the effect of increasing the rate of occurrence (RoC) or disruption duration of the breach from low to high on the impact a breach has on supply chain performance?*

Question 4: *Are the improvement strategies beneficial to the supply chain especially under disruption brought about by information security breach?*

Beyond this, the study also aims to establish the role of these strategic factors in either mitigating or exacerbating this impact. A mitigating role would indicate that such strategic factor can be used to dampen the impact of a security breach when it occurs and this can be a good addition to any proposed information security impact management strategy.

1.5.2.3 Study 3

This research posits that the type of cost impact examined in study 2 represents a direct cost assessment considered by most organisations which they use in decision making. However this study opines that there exist an indirect cost implication that also needs to be considered before making any strategic decision. The argument for this approach stems from the fact that the estimated cost impact is quite uncertain in itself and the complexity of the supply chain could exacerbate this uncertainty and make it more difficult for supply chain managers to predict future impact. The ability to predict future impact is a form of control that any manager would like to have as this control is key to effective management. Therefore, a supply chain with high impact uncertainty would require a higher monitoring and review control level because of the high uncertainty associated with predicting future impact, while that

with low uncertainty would require low level of control. Increasing or decreasing the monitoring and control level due to changing complexity has cost implications which is regarded as an indirect cost. The question arises; how does supply chain complexity affect the impact uncertainty level of an information security breach and what implication does this cost have on supply chain strategy decisions? This type of analysis has not been seen in past literature, at least to the author's knowledge, and this study aims to fill that gap. Finally, a decision framework is established that help supply chain stakeholders make strategic decisions based on both direct and indirect cost assessment.

1.5.3 Research Scope

The cost investigated by this study are operational costs, and do not include cost associated with damage to company's image or regulatory fines. The study investigates the impact each security breach has on supply chain cost performance such as inventory holding, backlog, and ordering costs only. It also examines the effect on supply chain performance measures such as fill rate and the ordering pattern of individual agents. While the holding cost, backlog cost, ordering cost and fill rate are common performance measures used in past literature, the examination of the ordering pattern is unique only to this study and is established in this study to have implication to the transportation strategy used in the supply chain. Due to the different complexities found in different supply chains, this study uses an analysis of the ordering pattern to inform the appropriate transportation (or shipping) strategy. By looking at the impact of these breaches on supply chain performance, including the entropy assessment, one can begin to understand the dynamics of these security incidences in order to plan for an effective prevention-mitigation-correction strategy mix that suits the overall organization and supply chain management goal.

1.6 RESEARCH APPROACH AND FRAMEWORK

The framework for this study is shown in Figure 1.1. This is discussed in more details in the methodology section.

To answer some of the questions stated above, this study proposes the use of discrete event simulation (DES). DES is one of the three types of dynamic simulations that is most widely used in Management Science (Pidd, 2003). This approach employs computer simulation which makes it possible to mimic changes that occur, through

time, in real life systems by using model representation in order to understand, change, manage and control such systems. The output of the simulation represents a direct cost assessment of information security breach impact.

This study also utilizes the concept of entropy theory to measure the degree of uncertainty or perturbation the incidence of each breach type (or threat) introduces to the supply chain and its members and how this affects supply chain decisions. Entropy according to Shannon (1948), who first coined the term in information theory, is a quantitative measure of uncertainty. Entropy scores are calculated for each threat (as will be explained in the Methodology section) and its implication to monitoring and review cost is established. This represents an indirect cost assessment.

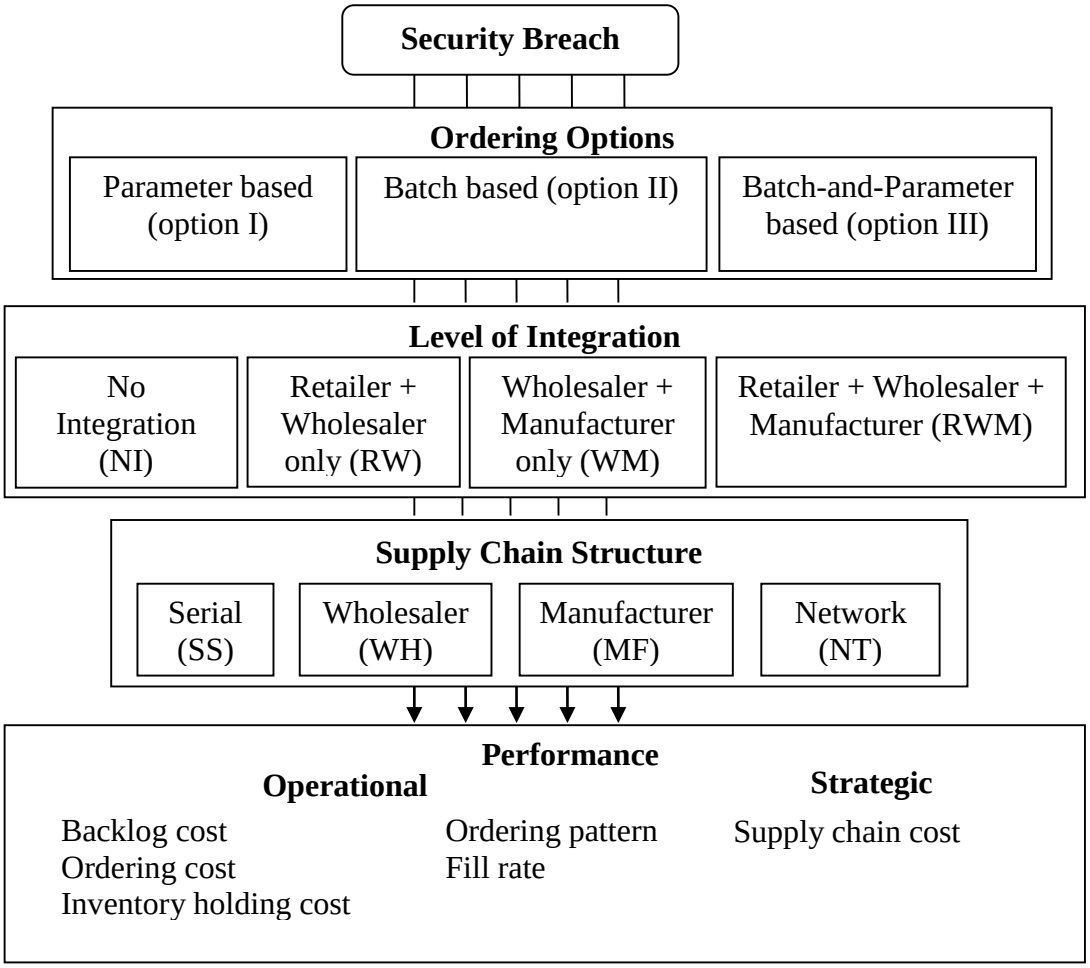


Figure 1.1 Research Framework

1.7 STRUCTURE OF THE THESIS

This thesis is organized as follows.

Chapter 2 reviews past works that forms the rationale for this study. It explains the gaps in literature and offers a description of the strategic factors considered in the study. The need for entropy assessment is also discussed.

Chapter 3 is the methodology part which describes the simulation approach. The conceptual and computer models are discussed here along with the various computer experiments. This chapter also describes the entropy assessment methodology which is one of the significant contributions of the study.

Chapter 4 discusses the result of the simulation experiment under all non-breach scenarios. The influence of each strategic factor is evaluated along with the interaction effect of all three factors on supply chain performance.

Chapter 5 examines the impact of information security breach on supply chain performance under various supply chain context. The effect of structural reconfiguration and information sharing level on breach impact is evaluated both separately and in combination. A framework for best strategy is given and the rationale for stepwise adoption is established.

Chapter 6 reveals the result of the entropy assessment of information security breach impact. The uncertainty level in each supply scenario is discussed and the effect of structural reconfiguration and information sharing level in raising or decreasing the uncertainty level is also discussed. The implication of uncertainty level change to monitoring and review efforts and the cost consequence is debated. Finally, a framework that justifies the inclusion of entropy assessment in supply chain breach mitigation decisions is established.

Chapter 7 concludes and summarises the theoretical contribution of the study. The managerial implication of the main findings is also discussed. Finally the limitations of the study and recommendation for future work are given.

Chapter 2 LITERATURE REVIEW

Concerns over the efficiency and effectiveness of supply chain operations have been raised over the years by academics as well as practitioners. These inefficiencies have been perceived to be as a result of uncertainties in key aspect of operations, which affect the flow of information and material along the supply chain. For example, uncertainties in demand, supply and processes for a long time, have led to distortion in the accurate capture of demand information and the ability to respond to them in a timely and efficient fashion. Traditionally, due to the absence of the integration initiative at the time, most members in each tier of the chain relied on historical demand or order data to forecast future demand. The traditional forecasting method could not accommodate the uncertainties of demand. As a result, supply chain members had to order and produce surplus to be able to accommodate these uncertainties. An interesting pattern emerged as the forecasted demand was amplified the further you go upstream the chain (Lee et al., 2004). The consequence of this action was that there tend to be more inventories in store than is needed, which can be very costly and even worse if the products are perishable. These uncertainties have led to poor performance of the supply chain and the reduction in the quality of product and/or services offered.

2.1 SUPPLY CHAIN MANAGEMENT - FROM COMPETITION TO COLLABORATION

Traditionally, Supply Chain Management (SCM) focused around the manufacturer and their immediate suppliers, but in today's world, SCM focuses on the optimization of all movement of goods and/or services, starting with the suppliers' supplier all the way through to the customers' customer (Plenert, 2002). In other words, firms have seen the need to manage the physical flows and the information flows up and down the supply stream in a coordinated manner. Therefore competition in the global market place has grown from inter firm competition to a highly efficient collaborative supply chain network within and between industries (Lancioni et al., 2003). Organisations no longer relate to suppliers in a competitive manner and have adopted a collaborative approach where an organization aligns itself or some of its business functions with those of its counterpart-suppliers. Suffice to say, supply chain management has seen a paradigm shift from competition to

collaboration and this shift is premised on the need for improved efficiency and effectiveness in the supply chain.

2.1.1 Managing Supply Chain Uncertainty through Information Sharing

It is quite apparent that the world is currently in the information age and consequently business should be conducted with this in mind. A business would thrive if it can position itself to leverage as much relevant information as possible. Several studies have shown that supply chain performance can be improved, not only by sharing demand information, but other types of information such as production; inventory; capacity; and lead time information, as you go upstream (Mukhopadhyay and Kekre, 2002, Kulp et al. , 2004, Devaraj et al., 2007, Yu et al., 2010, Lau et al., 2004). This enabled supply chain members to keep just the amount of inventory needed to efficiently cater for demand. The idea of information integration (in which IT is used to leverage operational activities) emerged as the new paradigm. As these IT technologies evolved, it later became apparent that it was not just enough to share relevant information but that the information being shared should be of good quality and be passed in a timely manner to help mitigate the effect of supply chain uncertainties (Bourland et al. , 1996, Wiengarten et al. , 2010).

2.1.2 Business and the Information Integration Paradigm

Information Technology (IT) has been the tool used by organizations (large or small) to greatly enhance their business operations via efficient information exchange. Information technology especially has been extended to increase the amount of benefits it can offer. For many years now technology has seen various developmental phases and the benefits derivable from its use has driven its further development. There have been massive improvements in the way organizations integrate business functions (and or processes) internally and externally with other business partners via electronic link. As described by Waters (2006), internal integration has been improved by tracking individual packages using bar codes, magnetic stripes and radio frequency identification (RFID) (Belal et al., 2008); monitoring vehicles through telematics; controlling warehouses through automatically guided vehicles; monitoring transactions and planning operations – and a host of other functions. In the same vein, external integration has been extended by allowing vendor-managed inventory (VMI); collaborative planning, forecasting and replenishment (CPFR);

synchronized material movement through the whole supply chain, payments by electronic fund transfer (EFT), roadside detectors to monitor traffic conditions and route vehicles around congestion – and so on. This integration, internal or external, is premised on uninterrupted communication or information sharing.

Communication between businesses has greatly improved over the years with the use of Information Systems (IS) such as Inter-organizational Information Systems (IOIS) and huge efforts have been invested into communication with customers as well. Fuelling this agenda is the plethora of investigations into the benefits of communication and information sharing that can be found in literature (Bourland et al., 1996, Chan and Chan, 2009, Cheng, 2010, Kristal et al., 2010, Li et al., 2006, Li and Lin, 2006, Yang et al., 2011, Zhou and Benton Jr, 2007, Yu et al., 2001, Raschke, 2010). Many researchers have looked into information sharing between businesses and their customers (B2C) while others have examined it in terms of business to business (B2B) (Mukhopadhyay and Kekre, 2002, Li et al., 2006, Humphreys et al., 2001, Zhou and Benton Jr, 2007, Yu et al., 2001). However, from the supply chain perspective information sharing is considered from both the B2B and B2C point of view.

At a network or supply chain level, competiveness is no longer a case of sharing information but how efficiently it can be transmitted. The development in Information Technology (IT) seriously helped this course as the introduction of Information systems such as Electronic Data Interchange (EDI); World Wide Web (WWW); E-Commerce systems and especially the Internet has aided the timely exchange of data (Gunasekaran and Ngai, 2004). This not only helped mitigate the effect of supply chain uncertainties but enabled intra-organization information sharing as well as inter-organization transactions (Kappelman and Richards, 1995).

2.2 GROWING USE OF THE INTERNET

According to some experts, complexity of the supply chain is increasing, profoundly fuelled by the growing level of internet use and integration initiatives, as evidenced by the number of networks current IT systems are supporting (Yami et al. 2010). Due to its ubiquitous nature, the internet is being employed in multidimensional and multifaceted ways in various supply chains to improve the quality of information and integration initiatives. Irrespective of the type of supply chain, the internet has

proven to be limitless in the purpose it can serve provided its use had been carefully or strategically planned. Its use has ranged from communication information exchange (Hart et al. , 2000) to more operational related functions such as order filling, purchasing, human resource management etc. (Lancioni et al. , 2003). These systems are increasing in the level of support and function provided and the cost of their application is increasingly becoming inexpensive where many small and medium size enterprises can now afford technologies that were beyond their reach due to lack of affordability. An example of this is the concept of cloud computing which is a somewhat recent development in the way IT is being exploited. It is a way of accessing hardware or software resources, or a combination of both, anywhere in the world by an organization or an individual via the internet.

2.2.1 Cloud Computing- Internet Use Example

At the most basic definition, cloud computing entails using computing resources such as computer applications and programmes over the internet as opposed to license-and-install on the desktop (Buttell, 2010). Leveraging Information Technology (IT) can be costly and has deterred small to medium scale organizations from using it. This in part has led to the emergence and justification for the somewhat new IT concept called 'cloud computing'. The emerging trend of enabling IT systems on the platform of cloud computing has been a subject of discussion in recent years. A purely functional definition of cloud computing is that it is a way of accessing hardware or software resources, or a combination of both, anywhere in the world by an organization or an individual via the internet (Amir, 2009, Smith, 2009, Armbrust et al. , 2010). These resources are shared amongst many users, abstracted, available on demand, scalable, and configurable (Marston et al. , 2011). Although this is not an entirely new concept, its unique feature where resources are pulled as opposed to being pushed makes it a more promising concept than its predecessors; time sharing in the 1960s and application hosting in the 1980s (Amir, 2009, Cusumano, 2010). Its applicability would entail seeing this concept being delivered over different service configurations. There are three basic service configurations also known as cloud service models which are Software as a Service (SaaS), Platform as a Service (PaaS) and Infrastructure as a Service (IaaS). In SaaS, the cloud user buys the right to use a working application hosted by an external provider via the internet. The PaaS model involves the use of an externally provided

infrastructure to host the application, while IaaS model requires the use of servers provided externally for raw computing, storage and network transfers (Durkee, 2010, Subashini and Kavitha, 2011). One can also look at the scope of the service whether it is purely open to the public (Public Cloud) or restricted to certain users (Private Cloud) or a combination of both (Hybrid Cloud).

2.2.2 Benefit of Cloud Computing

The result of an information security survey by Ernst & Young (2011) reveal close to half of the total number of respondents from 56 countries have either deployed or are evaluating cloud computing. This suggests that a significant amount of organisations are now using or close to adopting cloud computing which in a way puts pressure on others to follow suit. A summary of the opportunities organisations can avail themselves to when they enable their IT on the cloud and the various concerns associated with this new concept is shown in Table 2.1.

Cloud computing has several benefits over traditional IT models reported in literature. Cloud services bring flexibility, configurability, cost effectiveness, low implementation cost to IT and SCM. Primarily it offers a cost advantage to firms especially the small to medium scale enterprises who otherwise cannot afford the huge financial commitment required for deploying typical cutting edge enterprise-level IT systems such as Enterprise Resource Planning (ERP) systems (Marston et al., 2011). This is achieved through the metering system based on the notion of "pay as you go". Other benefits include taking away the associated costs of IT such as; system upgrades; recruiting and training IT staff; equipment delivery and installation; or modification of IT facility, from the Cloud user (Smith, 2009). It also helps to prevent the loss that would otherwise be incurred when an organization is unsuccessful in deploying an expensive in-house information system (IS). This is because its flexible feature makes it possible to change from one cloud service provider to another without any major cost to the user. If a service provider does not deliver an agreed level of quality of service (QoS), the service user may change to another provider offering a better or even cheaper service. These advantageous features of Cloud computing can help organizations or supply chains to be lean, agile or both (le-agile), responding effectively to demand. However there are some concerns over its adoption with data security being the chief of those concerns.

Propellants for Adoption	Barriers to Adoption
Elasticity/scalability: the ability to scale IT infrastructure requirements both up and down rapidly	**Corporate culture shock**: going from internal provision to external provision
Flexibility: ability to purchase software components from oracle, Apple, SAP etc and combine it to form a business solution	**Quick provisioning:** being able to scale computing resources up or down at the level of automation
Pay-as-you-go: pay-per-use basis versus install-and-own.	**Loss of control**: managing IT infrastructure through service level agreements (SLAs) with Cloud Service Providers (CSPs)
Cost savings: reduction in IT operational cost	**Information security**: How safe is your information and data from security threats?
Stepwise adoption: ability to decompose an entire technology into piecemeal sizes and gradually adopt it in stages	**Privacy concerns**: safeguarding personally identifiable information of employees, business partners and customers and meeting legal and ethical requirements regarding privacy regulations
Infrastructure utilization: virtualization of hardware and software resources as a service to multiple users simultaneously	**Regulatory compliance**: conforming to the regulations of the part of the world where hardware and software is located
Reducing market barrier: reduction of IT barriers to market entry. IT that was unaffordable before can now be utilised over the cloud.	**Specificity**: has to do with compatibility issues and data lock-in.
Security: delivering "security as a service"	**Lack of standards**: lack of commonality in interoperability among cloud providers and between enterprise systems and cloud services

Table 2.1 The opportunities and threats to cloud computing adoption

2.3 MANAGING INFORMATION FLOW DISRUPTION

It is very evident that nowadays, the flow of information is crucial to business survival. For materials to move down the supply chain there has to be a prior

movement of information up the chain. A disruption in this flow of information would have an effect on the movement of materials down the chain and hence lead to customer dissatisfaction. It is not surprising that a study by Munoz and Clements (2008) suggested that information flow delays play a larger role as a contributor to lost sale revenues in the supply chain than material delay does. There is of course a pressing need for operations managers to carefully protect and manage the flow of information and plan appropriately for disruption in this flow. It stands to reason therefore that while IT has been effective in curbing the effect of supply chain uncertainties; IT (in itself) introduces inherent uncertainties to the supply chain. Traditionally, the focus has been primarily on the uncertainties enveloping the supply chain. However there is an increasing awareness of the unique uncertainties that IT introduces to supply chain operations in the form of security risks. These unique uncertainties represent the possibility of an incidence of threat which might compromise the functioning of information systems (IS) and interrupt operations leveraged by such systems. The security of any IS is pertinent to obtaining the purported benefits derivable from its use. A secure system implies that there is no possibility of disruption in operations with which the system is being used to leverage. However, in practice, no system is totally secure as every system is susceptible to breach.

Threats to the security of an IT system are becoming increasingly sophisticated and may result in loss of integrity, disruption of service and/or loss of confidentiality (Stoneburner et al. , 2002). Nonetheless, security controls appear to be lagging behind the use of new technology (Baker et al., 2010, Potter and Beard, 2012). As security breach comes in various forms, the quality of information or even the accessibility to information can be compromised. This may result in delayed transmission which might reduce the relevance or value of the information, or altogether jeopardize the accuracy of the shared information. Therefore appropriate countermeasures should be implemented. However, various countermeasures which protect information systems from threats exist in practice, some more expensive than others. As a result, organizations engage in risk management, which informs their choice and level of countermeasure based on an assessment of risk incidence and cost impact.

2.3.1 Types of Information Security Breach

According to Vinod et al. (2008), ISO27001 mandates that the potential threats to the system and assets be identified in compliance with control A.7.1.1 (inventory of assets), and this can be done by using an appropriate threat database. Several databases exist that contain data on information security breach collected from various organisations in the form of surveys. A survey done by PricewaterhouseCoopers in conjunction with Infosecurity Europe, under the auspices of the Department for Business Innovation and Skills (BIS), called The Information Security Breach Survey (ISBS) 2012 reported some security breaches experienced by various organizations. These include: Systems failure or data corruption; Infection by viruses or malicious software; Theft or fraud involving computers; other incidents caused by staff; attacks by unauthorised outsider including hacking attempts (Potter and Beard, 2012). These breaches can be grouped under internal-based, external-based or platform-based. The internal based security breaches are those resulting from deliberate or in deliberate actions of staff and members of the organization. External –based breaches include those perpetrated by outsiders who are not members or staff of the business. This security breach can be worm; virus or malicious software attack. It can also be password sniffing/cracking software; spoofing (either IP spoofing or web spoofing) attack, denial of service attack (email bomb attack or Ping O'Death), or direct attack (hacking) (Warren, 2000). Lastly the Platform-based incidences are caused by the service provider. Examples of this include; systems failure or data corruption resulting from poor resource management or over committing computing resources (Durkee, 2010), policy violations or physical damage or theft of the resources.

A survey done by Verizon Risk team joined by United States Secret Service (USSS) also revealed some breaches faced by organizations and reported that 70% of data breach was caused by external agents, 48% by insiders and 11% implicated business partners (Baker et al. , 2010). Whitman (2003) proposed 12 categories of security threat, namely: Act of Human Error or Failure (accidents, employee mistakes); Compromises to Intellectual Property (piracy, copyright infringement); Deliberate Acts of Espionage or Trespass (unauthorized access and/or data collection); Deliberate Acts of Information Extortion (blackmail of information disclosure); Deliberate Acts of Sabotage or Vandalism (destruction of systems or information);

Deliberate Acts of Theft (illegal confiscation of equipment or information); Deliberate Software Attacks (viruses, worms, macros, denial of service); Forces of Nature (fire, flood, earthquake, lightning); Quality of Service Deviations from Service Providers (power and WAN service issues); Technical Hardware Failures or Errors (equipment failure); Technical Software Failures or Errors (bugs, code problems, unknown loopholes); Technological Obsolescence (antiquated or outdated technologies).

These forms of security breach cause disruption in business processes and may ultimately lead to loss of business. They can cause systems to crash preventing suppliers and other Supply Chain members from having access to the service, hence disrupting the flow of transactions leading to loss of money amongst other intangible yet crucial losses. Depending on the form of attack, the magnitude of the impact of such failure can be colossal and highly detrimental to Supply Chain performance.

2.3.2 Consequence of Information Security Breach

Security concerns as it relates to information sharing are privacy, protection of proprietary information, and preservation of the quality of information. According to Wiengarten et al. (2010) information quality plays a pivotal role in the success of collaborative practices, and this is due to quality factors such as timeliness, accuracy, relevance and added value of the shared information. Rees et al. (2011) described three types of losses an organszation faces when they experience data breach: damage to a company's image, regulatory fines e.g. fines paid to Health Insurance Portability and Accountability Act (HIPAA) due to non-compliance to regulation, and production losses as a result of disruption in production's IT support. The National Institute of Standards and Technology in their 2002 report described three types of impact on IT systems: loss of integrity, loss of availability and loss of confidentiality (Stoneburner et al. , 2002). This paper aims to investigate the impact of loss of availability or disruption due to security breach on the performance of business operations.

2.3.3 Use and Reliability of Information Security Breach Survey Data

There have been several arguments as to the reliability of quantitative data on security. Some have argued that most organisations that have taken part in surveys cannot themselves attest to the fact that the information provided is near perfect.

Some have been heard saying they just had to put down a rough estimate (Rees et al., 2011). Adding to this is the fact that incidence of security breach changes from year to year some worse than others. It is believed that many security breaches go unnoticed perhaps due to a poor monitoring system or the absence of it. Corroborating this assumption is a survey by Baker et al. (2010) which revealed that 61% of data breach was detected by external parties. Organisations therefore need to adopt a proactive approach rather than a reactive one to managing security. An organisation needs to be able to detect any incidence of security breach within its premises and must be able to log it. The ability to profile these breaches and recognize 'hot spots', as these changes yearly, is paramount in establishing a formidable security policy. Due to the rising level of sophistication hackers and other fraudulent agents carry out their attacks, what might seem less harmful to an organisation a few years ago might become the bane of existence.

Besides profiling the occurrence of breaches within an organization and learning from one's failure, it is equally important to learn from the failure of others. This is why surveys are important so that one can make decisions not just based on one's internal data but on the likelihood that external data represents. According to Mitroff and Alpaslan (2003) in Altay and Ramirez (2010), 95 percent of Fortune 500 companies are unlikely to be able to manage a disruption that the company has not experienced before because they are ill-equipped. This is because many organisations are not proactive towards information security breach and are quite complacent towards a breach type that occurred in another organisation but not theirs. However, according to a survey by Mitroff and Alpaslan (2003), proactive businesses existed for an average 16years more than their reactive counterpart. This goes to show that organisations need to learn from the failure of others and put appropriate security measures in place to avoid being caught unprepared. Many organisations are now using multiple sources in evaluating security threats (Potter and Beard 2012). Although sometimes they may be restricted in terms of reliability, security surveys give a good picture of the types of security threats faced by organizations from different industrial sectors, a careful analysis of these data might give invaluable insights. This is valuable information and should not be disregarded on the account of reliability. Giving credence to this, the United States Secret Service pooled resources together with Verizon Risk Team to come up with an

investigative report on data breach in 2009. Similarly, PriceWaterHouseCoopers in conjunction with Info Security Europe, under the auspices of the Department for Business, Innovation and Skills (BIS), conducted an information security breach survey in 2010, although this has been organized in the past by BIS and its predecessors (DTI and BERR) every couple of years since the early 1990s. There are other surveys that aim to provide a rich pool of data on security breach. Organizations need to realize the importance of other sources of information security practices and incidents other than their own.

A study by Gordon et al. (2003) revealed that sharing security information with partners helps to reduce the amount each firm spends on information security activities. The view that no quantitative analysis should be done due to the unreliability of security data, as it can change from year to year, has been suggested by Rees et al. (2011) to be a minority view.

2.3.4 Risk Management

Threats to information security bring an organization to the possibility that their operations would be disrupted and their data compromised. This possibility, also referred to as risk probability, is defined as the probability of incidence of a threat and is different for each threat (Kaplan and Garrick, 1981). In this study risk is defined as the likelihood of a threat occurring (in this case Information security breach) having either a negative or positive impact (Gerber and von Solms, 2005) on a firm or supply chain. For the purpose of clarity, throughout this study, risk is contextualized as the chance that a particular IT-related breach will occur and compromise the security of information which in turn impacts the performance of an organization in a negative way. Each breach is conceptualized as an incidence of each form of threat and represents different risks to an organization. Examples of these are systems failure or data corruption; infection by viruses or malicious software; theft or fraud involving computers; other incidents caused by staff; attacks by unauthorised outsider (including hacking attempts) etc. (Potter and Beard, 2012).

In risk management, all risks that the organization potentially faces are identified and assessed, and the appropriate strategy is implemented to manage the incidence of these threats (Stoneburner et al. , 2002). In coping with risks, organizations use all or any combination of the following strategies: risk prevention and deterrence (also

called Prevention); risk detection and recovery (also called Mitigation), and risk correction (also called Monitoring and Review) (Ouyang 2012). These strategies involve management or administrative, operational and physical, technical or logical tools. According to Ouyang (2012a), Management or Administrative tools include policies; standards; processes; procedures; and guidelines. Operational and Physical Control tools include execution of policies; standards & process; education and awareness; program security; personnel security; document controls; facility or infrastructure protection etc. Technical or Logical controls include, but are not limited to, access controls; identification and authorization; confidentiality; integrity; availability; non-repudiation.

According to Ouyang (2012), risk prevention deals with protective measures put in place to prevent the occurrence of breach or deter perpetrators from attacking. This is perhaps the first line of defense. An example of this is installing firewall or security software. However this might not be very effective as breaches do still occur. The second strategy which is the mitigation strategy helps to reduce the impact of the incidence of breach when it occurs. A mitigating strategy would entail repair of damaged assets, initiatives to restore integrity and reputation after the incidence of threat, and efforts to bring back lost customers. For instance, backing up data on another system can help an organization retain accessibility to valuable data in the event of a compromise to the current system. It is more or less a recovery contingency plan to keep the business going or to restore the operations of the business to full functionality after severe attack. Choosing one or any combination of these response strategies requires an earlier assessment of the threats an organization is exposed to in terms of occurrence and cost impact (Rees et al 2011). The cost impact is determined *a priori* and this is poorly estimated as it reflects more direct costs and less indirect costs. The indirect costs such as loss of control are hard to estimate and most studies in literature tend to ignore this when estimating the impact on a business.

2.3.4.1 Risk Assessment

Being proactive requires rigorous risk assessment. However there are some limitations on the components of risk assessment. Reducing vulnerability to threats require the implementation of appropriate risk strategy which is informed by adequate risk assessment. To assess any risk, the probability of incidence (P) is

multiplied by the cost impact (*I*) on the organization if it occurs (Deane et al. 2009, Rees et al. 2011). These two components of risk assessment, *P* and *I*, have limitations as estimating *P* is very difficult due to unpredictability[3] and estimating *I* is also very poorly understood. The inconsistencies in *P* and *I* result in poor assessment of risks and could result into a Type-1 error or a Type-2 error (Banerjee 2009). A Type-1 error (false positive) occurs when an insignificant threat is poorly assessed to be a significant one. Here, the organization wastes effort and resources by implementing unnecessary risk management strategy where monitoring alone would have sufficed. The Type-2 error (false negative) on the other hand occurs when a significant threat is seen as an insignificant one. The effect of this is that a less stringent strategy is implemented to manage the threat which would be ineffective and result in an unprecedented impact on the organization. It stands to reason that cost impact represents a higher interest to most organisations than the probability of occurrence. It is logical that if the impact is high and despite the probability of occurrence being very low, then such breach incidence is still a source of concern for the organisation. If, however, the probability of occurrence is high and the cost impact is low, then organisations may decide to forego the cost impact if it is not too significant. Therefore the focus of this study is on the cost impact estimation.

2.3.4.2 Inconsistencies in Estimating Impact, I.

The threat-type incidence, hacking, experienced by Sony's PlayStation Network (PSN) in 2011 affecting up to 77 million consumers reportedly compromised over ten million customer's credit card information and was to cost the organization $171 million in remediation. This impact cost has been suggested by experts to be a rather optimistic assessment and that the true impact might be in the region of billions of dollars. Sony's spokeswoman, Kumie Tanaka, was reported to admit that they could not estimate the true impact of the breach at the time as they were still 'figuring out' the impact on its earnings (Osawa, 2011). Further to this, two different experts Mizuho Investors Securities analyst, Nobuo Kurahashi, and Barclays Capital analyst, Yuji Fujimori, reported an impact of $1.25 billion and $2.74 billion respectively (Brightman, 2011). A difference of $1.49 billion in their estimates lends credence to

[3] Refers to the changeable nature of the number of times threat incidence occur and the uncertainty of whether or not it will occur.

the fact that Impact (I) is poorly understood, even by experts. An even bigger estimate was reported by Forbes Business Magazine in tune of $24 billion impact cost (Phillips, 2011). While it has been difficult to estimate the true impact cost on an organization, it is even more difficult to estimate that for a supply chain. It is therefore crucial to adequately assess each threat to determine the best strategy to manage it. In literature, most IT breach impact studies are qualitative and are restricted to an organizational level (Goel and Shawky, 2009). These qualitative risk assessment studies are subjective and lack consistency. On the other hand, some quantitative studies have looked at the impact of other types of threat (such as natural disasters) to an organization, and some to the supply chain. However, there is no quantitative study in literature that has investigated the impact of IT threat-type incidences on supply chain material flow operations.

2.4 DISRUPTION RISK ASSESSMENT

A number of studies have approached disruption risk in different ways ranging from conceptual, empirical, simulation, survey, case study and review or a combination of these (Rao and Goldsby, 2009, Olson and Wu, 2010, Rainer et al., 1991). Rao and Goldsby (2009) conducted an extensive review of supply chain disruption literature and created a typology of disruption types and sources. However, they did not mention IT itself as a source of disruption. Most risk studies have been primarily based on threats other than those from IT and information communication technologies (ICTs) while a few studies have suggested IT security as a potential risk to the supply chain (Schmitt and Singh, 2009, Kim et al., 2011, Rees et al., 2011). Table 2.2 shows a summary of work that has been done on disruption risk assessment at the organizational level as well as the supply chain level and delineates between those that have provided real and objective estimation of impact, I, of certain threats on business operation and those that have looked at specific IT security risks. The third column reveals the approach taken to undertake the study. From the last three columns of the table we see that no single study has covered all three aspects.

Authors	Subject	Approach	Impact study? Y/N	IT security incident? Y/N	Supply chain study? Y/N
Altay and Ramirez, 2010	Impact of disasters on firms in different sectors: implications for supply chains	Fixed effect regression	Y	N	Y
Schmitt and Singh, (2009)	Quantifying supply chain disruption risk	Monte Carlo and Discrete-Event Simulation	Y	N	Y
Deane et al., 2009	Managing supply chain risk and disruption from IT security incidents	Mixed Integer Linear Programming	N	Y	Y
Munoz and Clements, 2008	Disruptions in information flow: a revenue costing supply chain dilemma	Discrete event simulation of beer distribution game	Y	N	Y
Rees et al., 2010	Decision support for Cybersecurity risk planning	Genetic algorithm	N	Y	N
Whitman (2003)	Profiling threats to information security	Interviews and Survey	N	Y	N
Wilson (2007)	The impact of transportation disruptions on supply chain performance	Dynamic simulation modelling	Y	N	Y
Bellefeuille, 2005	Quantifying and Managing the Risk of Information Security Breaches to the Supply Chain	Descriptive research	N	Y	Y
Yeh and Chang, 2007	Threats and countermeasures for information system security: A cross-industry study	Questionnaires and Analysis of covariances (ANCOVAs)	N	Y	N
Goel and Shawky, 2009	Estimating the market impact of security breach announcements on firm values	Event-study methodology	Y	N	N
Craighead et al., 2007	The Severity of Supply Chain Disruptions	Multiple-method, multiple-source empirical research design	N	N	Y
Kim et al., 2011	The dark side of the Internet: Attacks, costs and responses	Explorative research	N	Y	N
Loch et al., 1992	Threats to information systems: Today's reality, yesterday's understanding	Questionnaires	N	Y	N

Table 2.2 Summary of some relevant disruption risk studies

A few studies have examined the impact of disruption on supply chain operations. While some of these studies have examined the effect of physical disruption such as natural disasters (Samir, 2008), interestingly, a few others have examined the effect of IT security incidents (Deane et al., 2009, Kim et al., 2011, Loch et al., 1992, Pisello, 2004). Some approaches have focused primarily on disruption effects (in terms of delay in information flow) on supply chain without any regard to cause (Munoz and Clements, 2008, Schmitt and Singh, 2009) while others have looked more specifically at how specific disruption types (threats) affect the supply chain (Altay and Ramirez, 2010, Craighead et al., 2007). While the former approach gives a more general assessment of the impact of disruption, the latter gives clearer understanding of the dynamics of threats and how they impact the chain. From Altay and Ramirez (2010) it is understood that disasters lead to disruption which affects all sectors of the chain but certain threats have more impact than others. This type of specific-threat impact study is not as common as one would expect in literature, specifically in the area of information security management. It is still not quite understood how the impact of various threats to information security on supply chain performance vary (especially inventory management performance). Although a few qualitative and quantitative studies (Whitman, 2003, Yeh and Chang, 2007, Bellefeuille, 2005, Goel and Shawky, 2009) have looked at this in a rather subjective way requiring managers to rank or score threats according to their perception, there is still a lack of objective measure of these variances. Deane et al. (2009) examined how risks originate from one business, due to poor countermeasures put in place to prevent it, and is being transferred to adjoining firms in the supply chain using mixed integer linear programming (MILP). While they termed the risks they studied IT security incidents, there was no evidence of specific threats to security being addressed and it is not clear how these risks affect the dynamics of the supply chain. In a similar work by Rees et al. (2011), specific threats were addressed and the financial impact for a given countermeasure was estimated. However, it was still unclear how these threats affect the operations of an organization, not to mention the supply chain. This threat-type impact study seems to be lacking in information disruption literature. To know how these threats affect the performance of the network is crucial to appropriate disruption risk planning and management.

Having reviewed literature, it was clear that there is a paucity of quantitative research on information security as a potential source of disruption. Out of those that have considered information security, a very few have tried to investigate how threats to information security impact the supply chain: some purely qualitative, others a mix of qualitative and quantitative. Of this few, none has investigated how these affect the operations of the supply chain at an operational and strategic level and how a breach in one organization affects others that are linked to it, although they have not experienced any breach in themselves. For instance it is not yet understood, in real terms, from these studies what the cost implications of security breach in an organization's procurement process are for supply partners. It is obvious that these breaches can cause delays in transactions between supply chain partners but it not well understood to what extent these delays will impact the operating cost of members further upstream or further downstream of the supply network. There are other key performance indicators that are affected such as ordering pattern which may ultimately affect the shipping strategy of agents in the supply chain, but to what scale are they affected? The understanding of how these impact not just an organization but other members of the network is crucial to successful network management or coordination activities. It has not been evidenced how the complexity or conditions of the supply chain affect the impact of information security breach on its operations.

Most security risk studies have been based on cost to an organization, and have provided ways in which an organization can make economic assessment of countermeasures available to them. While these studies have focused on direct costs, there is yet to be a study that presents real evidence on indirect costs to the organization. This indirect cost is discussed later in section 2.6.

2.5 MITIGATING ROLE OF SUPPLY CONDITIONS

The best solution to information security problems of course would be to have appropriate levels of prevention and deterrence; detective and recovery, and corrective measures (Ouyang 2012). Disruption duration is a function of the level of security breach detection and recovery measures (otherwise called mitigation measures). It is within reason that higher breach disruption duration means the detection and recovery level is not high enough. Lower disruption duration is

indicative of having near appropriate level of detection and recovery measures. On the other hand, rate of breach occurrence (RoC) is indicative of the required level of security breach prevention and deterrence measures (otherwise called prevention measures). Higher RoC means the preventive and deterrence measure is not at an appropriate level, and lower RoC means that the level of breach prevention and deterrence is high (Dai et al. 2012).

However, the incidence and type of security breach changes year in year out and as such, businesses should be able to contain any changes using an appropriate security management system that can analyse these changes (Potter and Beard 2012). Breaches that were no longer an issue a year ago, being mitigated by the security measures already put in place, might become a serious issue the next year rising from changes in the incidence and level of sophistication with which these breaches occur. In the same vein, breaches considered benign last year might become malignant the next year following an increase in the number of occurrence.

Although many have reported that collaborative practices such as information sharing are beneficial to the supply chain, others have shown that there are moderating factors which affect these purported benefits. For instance, high cost of making IT investment typical of bigger business ventures (Dermikan, 2010), quality of information shared- timeliness; accuracy; relevance and added value (Weingarten et al, 2010), mode of information sharing (Lau et al., 2002), contextual factors such as external pressure and internal readiness of the organization, amongst other related factors have been reported to undermine the benefits derivable from sharing information. From this mix of studies, one can begin to appreciate the role of preparedness and requisite understanding of one's business environment (both internal and external) in deriving the said benefits of any information sharing strategy. It is therefore within reason, to assume that that the same information security breach would impact supply chains in different ways due to the different operating variables (also known as complexity drivers) found in various supply chains.

2.5.1 Supply Chain Complexity Drivers

Several definitions of complexity exist in literature. Bozarth et al. (2009) defined complexity as the level of detail complexity and dynamic complexity exhibited by

the products, processes and relationships comprising the supply chain. Serdarasan (2013) defined it under static; dynamic; and decision making complexities. According to Serdarasan (2013), Static complexity connotes the structure of the supply chain, the variety of its components and strengths of interactions; dynamic complexity describes the uncertainty in the supply chain which involves the aspects of time and randomness; while decision making complexity involves aspects of static and dynamic complexities. A review of complexity drivers was carried out in the study of Serdarasan (2013) and the study listed various drivers which include, but not limited to, number/variety of suppliers, number/variety of customers, number/variety of interactions, conflicting policies, demand amplification, differing/conflicting/non-synchronized decisions and actions, incompatible IT systems. In a separate work by Hoole (2005), the study listed five complexity drivers (which was referred to as performance levers); configuration; management practices; external relationships; organisation; and systems. Wilding (1998) examined what he called the supply chain complexity triangle: deterministic chaos, parallel interactions and demand amplification. From these studies, it is very obvious that supply chain structure, decision making policies (ordering policy), and the level of information integration present in the supply chain are prominent common factors. Studying the impact of an element in a supply chain setting should therefore include these three variables and conversely, the influence of these three variables can be examined to see how they affect the impact of the said element.

2.5.2 Conceptualisation of Supply Chain Structure

Supply chain structure or configuration has been suggested as one of the most prominent performance lever that helps improve supply chain performance (Hoole, 2005). Configuration or structural complexity is mostly construed to mean physical asset and material flow in the supply chain (Hoole, 2005); hence improving supply chain configuration has been suggested as one of the most common methods for reducing supply chain uncertainties and improving performance (Childerhouse and Towill, 2003). Supply chain structure has been defined by many researchers based on several parameters. Randall and Ulrich (2001) defined structure in their work as a function of distance of production facility to target market and the extent of production to reach minimum efficiency. In their work, Stock et al. (2000) conceptualized structure as a function of geographic dispersion and channel

governance. Structure according to Xu et al. (2010) was defined in the context of how the manufacturer directs its capabilities. They defined three structures; a component supplier structure is one where the manufacturer produces components for the original equipment manufacturer (OEM); a monopoly structure where the manufacturer assembles the product under their own brand; and the dual distributor structure which is a combination of the previous two. This study, however, adopts the notion of structure found in Hoole (2005) based on the indication of *what* gets done *where*?'. According to Hoole (2005), the Supply Chain Operations Reference (SCOR); which is endorsed by more than 750 member organisations, breaks the supply chain into four process elements (plan, source, make, deliver). These elements are reflective of the role the retailer, distributor/wholesaler, and the manufacturer/supplier play in the supply chain. It seemed quite appropriate to include all these elements when defining a supply chain. Therefore structure in this study is defined in terms of 'how many agents are in each process element', and the retailer, wholesaler and manufacturer are all separate tiers in the supply chain. This three tiered structure is more representative of a supply chain than a two tiered supply chain, and on the other hand represents a simplified version of a four or more-tiered supply chain.

Some studies have looked at the effect of supply chain structure on the performance of supply chains (Beamon and Chen, 2001, Mills, 2004, Xu et al., 2010) but this has mostly been an evaluation of the performance of one multi-agent structure to another multi-agent structure. The performance of a simplified supply chain in the form of a serial structure against two or more complex supply chain structures with multi-agent components has not been studied, at least to the author's knowledge. This type of analysis is very important in complexity studies as simplifying the structure in certain aspects may help reduce the uncertainties associated with such highly complex supply systems. Beamon and Chen (2001) described four supply chain structures based on a single manufacturer present in the chain namely; convergent (assembly type), divergent (Arborescent type), conjoined (combination of convergent and divergent) and general (also called network). They then examined the performance of a conjoined supply chain structure while Lau et al. (2002) included a linear structure (also called serial) in addition to what was described by Beamon and Chen (2001) but they only considered the impact of information sharing

on a divergent supply chain in their study. It appears that many of these studies consider various supply chain structures with one thing in common; there is only one manufacturer in the chain, except for the network structure. In order to examine the effect of structure on supply chain performance, this study evaluates the relative performance of a distribution type, manufacturing type and network type structures to a serial counterpart in disrupted and non-disrupted supply chain scenarios. In addition the effect of structure on supply chain disruption has been under studied in literature. Study of the structure effect in the context discussed above is one of the contributions of this study.

2.5.3 The role of ordering options

Several studies have established the cost controlling effect of ordering policies in a supply chain. These policies determine the key inventory decision of 'when to order' and 'how much to order'. The 'when to order' decision is governed by certain conditions that need to be met before an organisation can place an order to its supplier. This could mean when the inventory position falls below a target level (re-order point) after periodic or continuous checks (Axsäter and Juntti, 1997, Axsäter, 2003), or when an order is received from downstream agents in the form of aggressive ordering (Papanagnou and Halikias, 2006) Agrawal et al 2009). The condition mostly used in literature and in practice to decide if an order should be placed is whether the inventory level falls below the predefined re-order point. This point could generally mean a target level that must be kept at all times but may be exceeded. The 'how much to order' can either be a predetermined quantity (batch ordering) (Baganha and Cohen, 1998, Axsäter, 2003, Mitra and Chatterjee, 2004, Tee and Rossetti, 2002) or the difference or addition between two or more decision variables or parameters (Agrawal et al., 2009, Banerjee et al., 1996, Chen et al., 2000, Chen and Disney, 2003, Wright and Yuan, 2008). The continuous review model, (Q, R), and the order-up-to (OUT) comprising of the base stock model (r, S) and the min-max (s, S) model, have been studied extensively. According to Vasconcelos and Marques (2000), in the continuous review (Q,R) option, Q is usually set to Economic Order Quantity (EOQ) and R is the re-order point computed for each replenishment period. The EOQ model being deterministic usually fails and causes a significant increase in cost when used in a stochastic environment. However Axsäter (1996) proposed an optimal solution for Q by multiplying the EOQ by

square root of $1+\alpha^2$ when $\alpha=2$. This optimal model is used as one of the ordering options in our simulation model. Another ordering policy commonly used in research is the base stock option (r, S) where r represents the review period and S the OUT level (Agrawal et al., 2009, Bensoussan et al., 2007, Beamon and Chen, 2001, Chen et al., 2000). The other option is the OUT (s, S) option where s is the re-order point and S is the order-up-to level (Chen and Disney, 2003, Lau et al., 2004, Arrow et al., 1951). Again we see from several studies that organisations perform differently under various ordering policies. In a study by Lau et al. (2008) they found that the EOQ model held the most benefit for the retailer while the periodic order quantity was more beneficial to the suppliers. However it is not evident from literature how these policies perform under information security breach.

2.5.4 Role of Information Sharing

Information integration results in interdependencies amongst supply partners where the upstream partners rely on key business information from downstream partners in a timely manner. Therefore disruption in this flow of information could have a negative effect on the movement of materials down the chain and hence lead to customer dissatisfaction. Alluding to this reality is a study by Munoz and Clements (2008) which suggests information flow delays play a larger role as a contributor to lost sale revenues in the supply chain than material delay does.

Information sharing (or information integration as it is also called in this study) has been a solution pushed by some research (Bourland et al. , 1996, Chan and Chan, 2009, Cheng, 2010, Kristal et al., 2010, Li et al. , 2006, Li and Lin, 2006, Yang et al. , 2011, Zhou and Benton Jr, 2007, Yu et al., 2001, Raschke, 2010). A good amount of research, both empirical and analytical, has been conducted in the area of information sharing and how agents in the supply chain derive benefit from it, if any at all. It has been reported that there exist benefit to members of the chain who engage in information sharing especially those types of information that are important to the timely operation of the chain such as demand, inventory, supply lead time and capacity information (Mukhopadhyay and Kekre, 2002, Kulp et al. , 2004, Devaraj et al., 2007, Yu et al., 2010). Although the benefit may be disproportionately distributed amongst supply chain members (Yao and Dresner, 2008), each member strives to position themselves in a vantage point where benefit

accrues to them. The question has been who stands to gain the most if information is shared, that is if there is any benefit to be derived at all. Therefore there has been discussion about ways to incentivise members or agents in the chain that do not directly benefit from information sharing (Yao et al., 2010).

2.5.5 The Need for a Systemic Study

There have been many studies looking at IS risks to an organization and a very few have studied IS risk to the supply chain. However there is yet to be an academic study on the impact of IS disruptions on the supply chain under various supply chain context or conditions. The supply chain context is defined here as the state of the chain in terms of the level of information sharing (information integration) present, the specific ordering option being used and the structure of the supply chain. Table 2.3 reveals a list of some of the previous studies and the supply chain context their work was based on. Three different contextual factors are considered in this study, namely ordering option; supply structure; and information sharing level. Each contextual factor or complexity driver has various alternatives. Under the ordering option, Table2.3 shows three alternatives that have been studied which are parameter based ordering (PBO); batch ordering (BO); and combined batch-and-parameter based ordering (CBPO). The supply chain structure is examined whether it is a serial type structure with only one agent in each tier of the supply chain or if there are multiple agents (multi-agent) in each tier representing a more complex structure. However the multi-agent type structure can also exist in different alternative forms such as distributor, manufacturer, or network type structures. Under the information sharing context, the table examined two alternatives, centralized and decentralized information sharing, although the centralized option can also exist in two alternatives: partial or full information sharing. It is clear that none have studied supply chain contextual effect under all three categories together. Some have examined the effect of these complexity drivers separately but there is a need to build as much context as possible in supply chain studies. Perhaps a change in one of these contextual variables in the supply chain may result in a completely different outcome when the effect of the other two is examined. Also, it is not clear what the interaction between the effects of two or more contextual factors is on supply chain performance. In addition, it is not evident from literature how this contextual effect

	Ordering Option			Structure		Information sharing	
Author	PBO	BO	CBPO	Serial	Multi-agent	Centralised	Decentralised
Papanagnou and Halikias (2006)		*		*			*
Chen (1998)		*		*		*	*
Banerjee et al. (1996)	*	*		*		*	
Agrawal et al. (2009)	*			*		*	*
Wright and Yuan (2008)	*			*			*
Chen and Disney (2003)	*			*			*
Hosoda and Disney (2004)	*			*			*
Chen et al. (2000)	*			*		*	*
Sterman (1989)	*			*			*
Wu and Edwin Cheng (2008)	*			*		*	*
Yu et al. (2001)	*			*		*	*
Lau et al 2002		*			*	*	*
Lau et al 2004			*		*	*	*
Chen and Samroengaja 2004	*	*			*	*	
Beamon and Chen	*	*			*		*
Chatfield et al. (2004)	*			*		*	*
Baganha and Cohen 1998		*			*		*

Table 2.3 Review of past contexual studies

or the interaction effect mitigates or worsens performance especially in an information security breach scenario.

2.6 ENTROPY ASSESSMENT AND THE INDIRECT IMPACT COST PARADIGM

While the direct cost impact of a security breach on two different organisations/supply chains might be the same, the level of uncertainty associated with such impact may not be the same due to the different complexities of both organisations/ supply chains. In other words, the direct cost impact when the breach occurs at another period in the same year might be different for both organisations/supply chains. It is therefore necessary to capture this uncertainty and this can be done using an entropy approach.

2.6.1 The Supply Chain Scenario Narrative

Consider a scenario where a supply chain contains the retailer, distributor, manufacturer and supplier and it is known that information about demand flows from the retailer through the chain to the manufacturer, which uses this information to place orders to its supplier. Depending on the level of integration, supply partners can access this information once they have access to the internet and plan their operations effectively in a timely manner. Intuitively, one knows that if the system, which the retailer uses in capturing demand, is compromised due to an attack that makes service unavailable, the other parties in the supply chain would be denied the advantage of knowing demand as it occurs or even denied access to real demand information because the database has been corrupted. Consequently, they would have to rely on forecasted demand in making ordering decision with their suppliers and cannot take advantage of having timely demand information. Bourland et al. (1996) revealed that a supplier could reduce inventories and its associated costs or improve the reliability of deliveries to its customers given more accurate demand information.

On the other hand if a system, with a customer interface, which allows a customer to place an order to the retailer or manufacturer directly, becomes unavailable due to security breach, or crashes due to a sudden increase in the number of customers accessing the interface at the same time. The organization or supply

chain might lose that customer depending on the severity of the incidence. Severity here means the duration of the breach and the number of repeated occurrences. According to Hoffman and Lowitt (2008), retaining customers is critical to survival of an organization, let alone growth. Assume, hypothetically, that a web service where customers are able to place their orders online is compromised and has become inaccessible to customers. This in effect will result in the customers defecting to use services provided by competitors. The customers are classified into two categories which are the 'loyal customers' (which are those accustomed to the use the service and regularly patronize it) and the 'likely customers' (which are trying the service for the first time and are looking for a reliable service to stick to). From Capraro et al. (2003) and Hennig-Thurau and Klee (1997) it is understood that loyal customers are still likely to purchase from vendors despite incessant dissatisfaction. However, a research conducted by Accenture revealed that 70% of US retail customers are loyal customers and that 85% of these "loyal" customers are willing to shop elsewhere if properly enticed (Hoffman and Lowitt, 2008). In other words, there is an 85% chance they could defect. Inaccessibility to service might be the defecting factor which could cause 'loyal customers' to defect and 'likely customers' to permanently defect. The breached organization would then have to spend more money on promotional packages, among other things, to win back customers.

The objective of any organization or supply chain would be to reduce the number of occurrences of security breach or totally eradicate it if possible. It is understood from the above that there is an 85% chance of losing customers or customer transaction if they experience incessant dissatisfaction caused by security breach of the system. As it has been established in section 2.3.4, one way of calculating the risk to an organization is by multiplying the probability of incidence (P) of the breach by the impact cost (I) incurred when that breach occurs (Rees et al., 2011, Deane et al., 2009). Therefore, the higher the probability of an incident occurring the greater the risk and vice versa. For instance if the cost incurred when an incidence occurs is £20k and the probability of occurrence is 0.5, then the risk impact is £10k. If the probability of occurrence reduces to 0.1 due to countermeasures put in place, then the risk impact becomes less, £2k. In the same light, if there is an increase in the probability of incidence then the risk impact increases. In essence once the cost

impact (I) is established, then all that requires monitoring is the probability of incidence (P). Ideally any preventive measure would be to reduce the level of occurrence of these breaches (i.e. P) and any mitigating measure would be to reduce the impact cost (I). However there is still a conundrum yet un-tackled. The pre-estimated impact cost is in itself uncertain. For example, the impact of a security breach may vary depending on the time of the year it occurs. It is expected that the same breach occurring during peak demand periods will have more cost impact than when it occurs during the less busy periods of the year. Therefore this uncertainty needs to be reflected in the risk calculations. A very well established means of estimating uncertainty is the entropy theory which is discussed in the subsequent section.

2.6.2 Entropy Assessment

Entropy has been described as a quantitative measure of uncertainty which describes the level of chaos or surprise associated with an event (Sivadasan et al., 2002, Shannon, 1948, Shuiabi et al., 2005). This concept has been applied in various ways in literature to capture performance (Martínez-Olvera, 2008), flexibility (Shuiabi et al., 2005), complexity (Frizelle and Woodcock, 1995, Frizelle and Efstathiou, 2002, Sivadasan et al., 2002), anonymity (Bezzi, 2007, Deng et al., 2007), trail disclosure (Airoldi et al., 2011) and so on. However this concept has not been applied to information security impact assessment in supply chain management studies despite its promising advantages over the use of just probability alone. While previous studies have estimated information security risks as a function of threat occurrence and the associated financial loss (Rees et al. 2011, Deane et al. 2009), only a few have employed the Entropy theory. Although the concept of using entropy as an approach to determine uncertainty has been used in literature by Frizelle and Woodcock (1995); Frizelle and Efstathiou (2002); Ronen and Karp (1994); Sivadasan et al. (2002); and Martínez-Olvera (2008), the closest previous studies have come to applying entropy in security studies has been in data privacy studies such as disclosure risk assessment (Airoldi et al., 2011), measuring anonymity (Bezzi, 2007, Deng et al. , 2007). The argument is that since complexity of a system (characterized as the uncertainty of a system) can be measured using an entropy approach (Frizelle and Woodcock, , 1995, Martínez-Olvera, 2008), and, the little is known about a random variable the more the entropy of that variable, hence the level

of entropy of a security breach can be determined once the probability of occurrence is known (Airoldi et al., 2011). By inference, since an information security breach can be modelled as a disruption in the flow of real time market demand information, the level of entropy introduced into the operation can be determined once the probability space of disruption occurrence is known. This study therefore proposes the concept of Total Entropy which encapsulates the unpredictability inherent in the estimation of security breach cost impact. This is explained in greater details in the methodology section.

The assessment here is to evaluate security threats using threat occurrence to work out the level of entropy each threat introduces into the system. This will help identify those threats that are hot spots to guide management decision in selecting appropriate countermeasures and mitigation solutions. While this study is not an optimality study, it provides a useful methodology to security risk assessment from a process based view where financial loss information is not known a priori. But first the impact of these threats needs to be established using a simulation approach to mimic real life operations.

2.7 SIMULATION APPROACH TO UNDERSTANDING SUPPLY CHAIN DYNAMICS

A very powerful tool in analysing real life situations is the computer simulation approach. A definition of simulation given by Shannon (1998) is "the process of designing a model of a real system and conducting experiments with this model for the purpose either of understanding the behaviour of the system or of evaluating various strategies (within the limits imposed by a criterion or set of criteria) for the operation of the system." This has been used extensively in literature because of its promising advantages. It has been described as an effective and practical tool in evaluating and analyzing, in great details, supply chain design and management alternatives (Swaminathan et al., 1998). It can prove to be more credible than most analytical approaches being that it requires fewer simplifying assumptions and as a result captures more of the true characteristics of the system under study (Lau et al., 2004, Shannon, 1998). It has been used in supply chain studies to understand impact of different variables on supply chain performance such as information sharing (Yang et al., 2011, Lau et al., 2002, Lau et al., 2004, Chan and Chan, 2009),

integration (Wang et al., 2008, Chan and Zhang, 2011, Zhang et al., 2006) and inventory management (Schwartz et al., 2006, Lau et al., 2008, Southard and Swenseth, 2008, Jammernegg and Reiner, 2007), to mention a few. This study focuses on information sharing as breach in information security is conceptualized as a disruption in the flow of information. According to Lau et al. (2004), a simulation approach has an advantage over an analytical approach in that the effect of information sharing on a supply chain can be investigated under various scenarios. Their work on the impact of information sharing on inventory replenishment offers a simple yet detailed model of supply chain interactions. In a similar work by Lau et al. (2002), they showed how various information sharing modes affect the dynamics of the supply chain and they presented a description of how the ordering policy is adjusted based on available information. These studies were limited to manufacturer's (divergent) supply chain. The current study aims to extend their work by including other supply chain structures such as retailer's supply chain, distributor's supply chain and supply network. These are explained in more details in the methodology section. Discrete event simulations (DES) are a powerful tool used in mimicking the dynamics of a real system as it evolves over time (Ingalls, 2008, Law, 2007). A multi-agent approach where each tier of the supply chain has at least one agent (or member as it is sometimes called) making decisions is quite representative of the real world situation, hence making it the approach of choice (Swaminathan et al., 1998).

2.8 SUMMARY OF MAIN RESEARCH GAPS

Having reviewed past works, it became apparent that some gaps still exist in literature and this thesis aims to fill those gaps. The main gaps are listed below:

- Several studies have examined the role of ordering policy, supply chain structure and information sharing/integration on supply chain performance separately, but no study has examined the combined role of all three strategic factors in a single study. The interaction effect of all three strategic elements is not well understood. Does the combination of the best alternative amongst each of the three strategic factors produce the best synergic effect? Or are certain combinations better than combining the best alternatives in each

category even if they do not represent the best choice under each category of strategic factors?

- Impact studies relating to information security breach are few and somewhat understudied. The interaction of the strategic factors in an information security breach scenario are not well understood. Much focus has been on what IT managers can do to reduce the impact of a breach but not much attention is paid on how the supply chain context can be strengthened and poised for minimal cost impact. Certain pertinent questions have not yet been answered. How does the ordering policy, supply structure or information sharing level respond to information security breach impact and what alternatives within each strategic factor constitute the most resilient combination or synergy to the impact?
- Most studies in the area of information management are subjective and based on subjective risk estimation. Amongst the few objective ones, none have looked more closely at the pre-estimated impact cost component of the risk evaluation, at least to the author's knowledge. It is generally assumed that estimating the impact of information security breach is quite uncertain due to various exigent factors and the effect of this uncertainty on supply chain priorities has not been studied. For most organisations this impact is measured against a threshold that the organisation deems significant without any regard for the uncertainty surrounding the estimate. Therefore an impact with a low cost amount may be considered insignificant and the organisation may decide to ignore such breaches. This study aims to demonstrate that disregarding the implication of this uncertainty may ultimately cost the organisation and lead to poor supply chain strategy decisions. Besides the above gap, no study has used entropy theory to measure the uncertainty surrounding the information security breach impact cost estimate.

Filling these gaps would be a reasonable step forward in the area of information security management and supply chain management. With respect to supply chain management, this study creates a better understanding of the impact of security breach on supply chain performance under different supply chain scenarios. This understanding will help businesses make better strategic decisions on supply chain configuration, ordering policy, and information sharing in order to make their supply

chains more resilient to information security breach impact. For information security management, this study develops a novel application of entropy theory to measure impact uncertainty which informs the level of monitoring and review required to offset such uncertainty. Changing the monitoring and review level has cost implications which should be factored in when estimating impact cost. Using this entropy assessment creates a more inclusive approach to impact assessment than other existing ones.

Chapter 3 : RESEARCH METHODOLOGY

Several approaches can be used to study the research questions posted in the introduction chapter. Analytical approach, surveys, interviews, case studies are all viable approaches to undertake the study. However, using these approaches would require tremendous amount of effort, time, and money due to the complex nature of the research. This is because the research requires the study of 240 distinct supply chain scenarios that are all subject to the same supply chain conditions. An empirical research for such a complex study is close to impossible. A very powerful tool in analysing real life situations is the computer simulation approach. Therefore simulation modelling becomes the obvious research approach.

3.1 INTRODUCTION

A definition of simulation given by Shannon (1998 p. 7) is "the process of designing a model of a real system and conducting experiments with this model for the purpose of understanding the behaviour of the system and/or evaluating various strategies for the operation of the system." This has been used extensively in literature because of its promising advantages. It has been described as an effective and practical tool in evaluating and analysing, in great details, supply chain design and management alternatives (Swaminathan et al., 1998). It can prove to be more credible than most analytical approaches being that it requires fewer simplifying assumptions and as a result captures more of the true characteristics of the system under study (Lau et al., 2004, Shannon, 1998). It has been used in supply chain studies to understand impact of different variables on supply chain performance such as information sharing (Yang et al., 2011, Lau et al., 2002, Lau et al., 2004, Chan and Chan, 2009), integration (Wang et al., 2008, Chan and Zhang, 2011, Zhang et al., 2006) and inventory management (Schwartz et al., 2006, Lau et al., 2008, Southard and Swenseth, 2008, Jammernegg and Reiner, 2007), to mention a few.

3.1.1 Two Main Types of Simulation

There exist two main types of simulation namely; the discrete event simulation (DES) and the continuous simulation. Continuous simulation entails the study of a system as it evolves through time without any break in simulation, while DES refers

to the study of a system as a discrete sequence of events with breaks in between events. The reason for allowing breaks in DES is based on the assumption that no changes occur during the break and, ideally, this makes it run faster than the continuous simulation counterpart. The use of either of the two simulation approaches would depend on the nature of the study. If the study is interested in understanding the dynamics of the system through time, then continuous simulation would be ideal but if the study is about understanding the system during various events that occur at different time instances, DES would be the choice. This study adopts the DES as the simulation of choice due to the fact that it is interested in understanding the effect of discrete events rather than continuous events.

Discrete event simulations (DES) are a powerful tool used in mimicking the dynamics of a real system as it evolves over time (Ingalls, 2008, Law, 2007). It allows users to do a comparison of different alternatives without interrupting the real system and also to perform powerful sensitivity or what-if analysis that enables them to make better planning decisions. A multi-agent approach where each tier of the supply chain has at least one agent (or member as it is sometimes called) making decisions is quite representative of the real world situation, hence making it the approach of choice (Swaminathan et al., 1998).

3.1.2 Structure of the Chapter

This chapter discusses the simulation model in terms of the conceptual model, data validity, the simulation model specification, the computerised simulation model, the experiments, verification and validation of the simulation model. Lastly the entropy concept in information theory is explained and the entropy assessment methodology adapted in this study is shown.

3.2 THE MODEL DEVELOPMENT PROCESS

A simulation model is developed through a series of steps that assures that the real system or problem entity is being adequately mimicked. This requires a thorough understanding of the real system and the objective for modelling should be clearly defined. These steps include but are not limited to conceptual modelling, computerisation of the conceptual model (model coding), experimentation and implementation (Robinson 2004). Other activities such as data collection and analysis, verification and validation are continuously carried out throughout each

stage of the simulation study. The first step in the model development process is developing a conceptual model. According to Sargent (2010) the conceptual model could either be a mathematical, logical or verbal representation of the system, or a combination of these, developed for the objectives of a particular study. The specification and assumptions in the conceptual model are carefully chosen to mimic what is obtainable in the real system. After the conceptual model development, this model is converted into a computerised model; which is a detailed written computer programme for implementing and running the conceptual model on a computer system for the purpose of conducting experiments on the simulation model. The computer model can be developed using commercial software packages or written by the user by means of a general programming language. Various scenarios of the computer model can be specified and run (experimenting) and the output is collected and analysed, and inferences can be made.

3.3 CONCEPTUAL MODELLING OF THE SUPPLY CHAIN

This study is interested in understanding the impact of information security breach on supply chain performance under various supply chain operating scenarios. The impact can be determined by comparing the performance of the supply chain in a non-breach situation to that of a breached situation. Therefore for each of the scenarios, a non-breached and a breached version of the simulation model is created. To do this, first a conceptual model of the non-breach version is developed for each ordering option, supply chain structure and information sharing level scenarios. The conceptual model developed in this study is explained in this section.

3.3.1 Modelling the Supply Chain Activities

The supply chain is conceptualised as a series of agents working autonomously to deliver goods to the end consumer. For simplicity the number of echelons within the supply chain is limited to three consisting of the retailer, wholesaler and manufacturer. The decision on when to order and how much to order is determined internally by each agent and each operates independently and strives to achieve the minimal operating cost possible. Depending on their position in the supply chain, each agent places an order to the upstream agent and the upstream agent delivers goods to the downstream agent. Essentially, the retailer experiences the demand from the end customer (market demand) and determines when and how much order

to place to the wholesaler. In turn, the wholesaler works out when to order and how much to order from the manufacturer. The manufacturer then produces the product and delivers it to the wholesaler who in turn determines the quantity of goods to deliver to the retailer and supplies it. The sequence of activities involved in determining when to order and how much to order for each agent is shown below.

Each agent makes their decision using key parameters (adapted from Lau et al., 2004) and these are shown in Table 3.1.

Parameter	Notation	Retailer	Wholesaler	Manufacturer
Market demand	D	*		
Order quantity	Q	*	*	
Production quantity	PQ			*
Mean of Orders from downstream agent	μ	*	*	*
Standard deviation of Orders	σ	*	*	*
Stock received by agent	SR	*	*	
Stock shipped by agent	SS	*	*	*
Stock from Production	SFP			*
On-hand inventory	OH	*	*	*
On-order/Pipeline inventory	OO	*	*	*
Backlog quantity	BL	*	*	*
Inventory position	IP	*	*	*
Transportation lead time	L		*	*
Production lead time	PL			*
Production Capacity	PC			*
Re-order point	ROP	*	*	*
Order up to level	OUT	*	*	*
New order quantity	NQ	*	*	
New production quantity	NPQ			*
Unit shortage cost	*b*	*	*	*
Unit Holding cost	*h*	*	*	*
Unit ordering cost	*o*	*	*	
Unit production cost	*om*			*
Fixed ordering cost	*f*	*	*	
Production setup cost	*p*			*
Safety factor	*k*	*	*	*

Table 3.1 Key Modelling Parameters

The table shows the parameters of operation and their mathematical representation (notation). The use of '*' is to indicate whether the parameters relate to a specific agent or not. For example Market demand (D) only relates to the Retailer and stock received by agent (SR) relates to the retailer and wholesaler only, while stock from production only refers to the manufacturer. To help distinguish between information

relating to other agents when describing the activities of a particular agent, subscripts x, and y are used. Subscript 'y' represents information relating to the upstream agent while 'x' refers to such parameters relating to the downstream agent. The sequence of activities and mathematical model is described as follows.

Step 1: At the beginning of each operating day, an agent receives stock delivered by upstream agent

The stock sent by the upstream agent is received at the current period by the agent after the transportation lead time of the upstream agent. This stock is received at the start of business.

$SR_t = SS_{y,t-L}$ (1)

For the manufacturer SS_y is replaced with SFP which is stock received from production after the production lead time.

i.e. $SR_t = SFP_{t-PL}$ (2)

Step 2: Update inventory position

Once the stock is received, the state of the on-hand inventory and the on-order inventory is updated as follows:

$OH_t = OH_{t-1} + SR_t$ (3)

$OO_t = OO_{t-1} - SR_t$ (4)

Then the inventory position is updated as shown below:

$IP_t = OH_t + OO_t - BL_{t-1}$ (5)

Step 3: Decides if an order should be placed and what quantity to order

A decision to order is made when the inventory position is less than the re-order point and the quantity to order (Q_t) at a given period, t, is governed by the ordering option adopted by the agent. This is discussed in section 3.3.2.1.

Step 4: Updates its on-order inventory

The order information above (if any) is passed to the upstream agent and the on-order inventory is updated.

$OO_t = OO + Q_t$ (6)

Step 5: Experiences order from downstream agent

The order information for that day is received from the adjacent customer (downstream agent) and this is added to the pending order previously placed to determine the new order quantity for that period. If the agent is the retailer, the adjacent customer is the end customer and the customer order is called market demand.

$$NQ_{x,t} = Q_{x,t} + BL_{t-1} \quad (7)$$

Step 6: Decides the quantity to deliver to fulfil order from downstream agent

Each agent tries to fulfil all demand/order placed by downstream customer. However whatever the agent is unable to fulfil is back ordered.

$$SS_t = Min\left(NQ_{x,t}, OH_t\right) \quad (8)$$

$$BL_t = NQ_{x,t} - SS_t \quad (9)$$

Step 7: Updates its on-hand inventory information

$$OH_t = Max(OH - SS_t, 0) \quad (10)$$

Step 8: Computes mean and standard deviation of orders

The mean of orders and standard deviation of orders is computed using the moving average (MA) technique. For the retailer the mean of orders is represented as mean of demand instead.

Step 9: Computes the operating cost for the day

The operating cost this study is interested in are the holding cost, the backlog cost and the ordering cost. These are computed using eq. (11), (12) and (13) respectively.

$$HC_t = h * OH_t \quad (11)$$

$$BC_t = b * BL_t \quad (12)$$

$$OC_t = p * Max(Q_t, 0) + o * Q_t \quad (13)$$

For the manufacturer, the fixed ordering cost is known as production set up cost (p) and the unit ordering cost is called the unit production cost (op). Each cost is computed at the end of the day and averaged over the effective simulation period

only. Another performance measure used was the daily fill rate of each agent as shown in eq. (14). This is expressed as a percentage. The average fill rate is computed only over the effective simulation period by adding all the fulfilled orders and dividing it by the total orders placed by downstream agents within the total effective period.

$$FR_t = SS_t / NQ_{x,t} \quad (14)$$

3.3.2 Modelling the Strategic Factors

This study is interested in understanding the impact of information security breach on supply chain performance and this is studied under three strategic factors which are ordering option, supply chain structure and information sharing level. Each strategic factor is studied under various alternatives or levels to understand how changing the strategy from one alternative to another would impact the performance of the supply chain under non-breach as well as breached situations. The various levels, or scenarios as it is also called, are described in this section and the mathematical model for each scenario under each strategy is explained.

3.3.2.1 Ordering Policy Decision Models

It is assumed in the simulation model that each supply chain agent orders from the upstream agent when the inventory position (also called installation stock) falls to the re-order point (eq. 15) and the magnitude of order is decided by the choice of ordering policy adopted.

$$ROP_t = \mu(L_y + 1) + k\sigma\sqrt{L_y + 1} \quad (15)$$

The safety factor (k) is computed using eq. (16) which gives the optimal value of k which is the solution to the standard newsvendor problem as expressed in Lau et.al (2002).

$$k = \Phi^{-1}\left(\frac{b}{b+h}\right) \quad (16)$$

The magnitude of order quantity could either be the difference between two specific decision parameters (parameter based) or it could just be a predetermined batch size (batch ordering), or a combination of both (batch-and-parameter based). These three alternatives have been used in different forms and studied separately in literature.

They have been used in periodic review models as well as continuous review models. Each of these three alternatives is considered in this study: (i) The first alternative which determines its order size by computing the difference between two decision parameters (parameter based ordering) is exemplified in this study with Ordering Option I- the order-up-to base stock policy; (ii) the second alternative of using predetermined batch size (batch ordering) is represented in this study as Option II- the optimal economic order quantity (EOQ*); (iii) the last alternative which combines the previous two alternatives in determining its order quantity (combined batch-and-parameter based ordering) is represented as Option III- the modified base stock policy with an EOQ component. The reason for using these three different ordering options is to establish that the best alternative in a non-breach scenario does not necessarily perform the best in an information security breach situation.

This study hopes to demonstrate that the magnitude and direction of the impact of information security breach will depend on the choice of ordering policy being used by the members of the supply chain. In order to facilitate a more accurate comparison of the three alternatives the review period under each policy was set to one day which means they can be classified as either periodic review models or continuous review models as long as they satisfy certain assumptions which will be discussed later.

3.3.2.1.1 Option I- The Base stock Policy

One ordering policy commonly used in research is the base stock option (Agrawal et al., 2009, Bensoussan et al., 2007, Beamon and Chen, 2001, Chen et al., 2000). Here, an order is placed to raise inventory to the base stock level (otherwise called order-up-to level, OUT) when the inventory position falls below the base stock level. This option is also called an adaptive model because the order-up-to level is recalculated every replenishment period. The ordering decision for this policy is shown in eq. (17).

$$Q_t = \begin{cases} \max(OUT_t - IP_t, 0), & IP_t < ROP_t \\ 0, & IP_t \geq ROP_t \end{cases} \qquad (17)$$

Where the order-up-to level (OUT) is the same as the value of the re-order point shown in eq. (15). The order quantity is determined by two decision parameters: the order-up-to level and the inventory position (Cimino et al., 2010).

3.3.2.1.2 Option II- The optimal EOQ policy

In a (R, Q) option, when the inventory position falls to the re-order point (R), a batch Q is ordered. However, according to Vasconcelos and Marques (2000), Q is usually set to Economic Order Quantity (EOQ) which is predetermined and R is the re-order point computed for each replenishment period. The EOQ model being deterministic usually fails and causes a significant increase in cost when used in a stochastic environment. However Axsäter (1996) proposed an optimal solution for Q. The standard solution for EOQ in a stochastic environment is given by eq. (18).

$$EOQ_t = \sqrt{\frac{2\mu f(b+h)}{bh}} \qquad (18)$$

However, according to Axsäter (1996), multiplying the EOQ by square root of $1+\alpha^2$ becomes optimal when $\alpha=2$. This optimal model is used as one of the ordering options in the current study.

$$Q_t = \begin{cases} \max(EOQ_t * 2.2361, 0), & IP_t < ROP_t \\ 0, & IP_t \geq ROP_t \end{cases} \qquad (19)$$

3.3.2.1.3 Option III- The Modified Base stock Policy

The other option is the modified base stock policy which is a min-max policy (s, S) where s is the re-order point and S is the order-up-to level (Chen and Disney, 2003, Lau et al., 2004, Arrow et al., 1951). OUT in option III is the sum of the re-order point and a simple EOQ, unlike option I, where OUT is the same as the re-order point. This model can be viewed as a combination of options I and II.

$$Q_t = \begin{cases} \max(ROP_t + EOQ_t - IP_t, 0), & IP_t < ROP_t \\ 0, & IP_t \geq ROP_t \end{cases} \qquad (20)$$

Again it is seen from several studies that organisations perform differently under various ordering policies. In a study by Lau et al. (2008) they found that the EOQ model held the most benefit for the retailer while the periodic order quantity was more beneficial to the suppliers. However it is not evident from literature how these policies perform under information security breach.

3.3.2.2 Supply Chain Structure Decision Models

The concept of structure in this study differs from past literature in that the supply chain structure has been defined in this study as a reflection of a singular

organisation, be it wholesaler or manufacturer, serving more than one upstream and/or downstream agent and is shown in Figure 3.1.

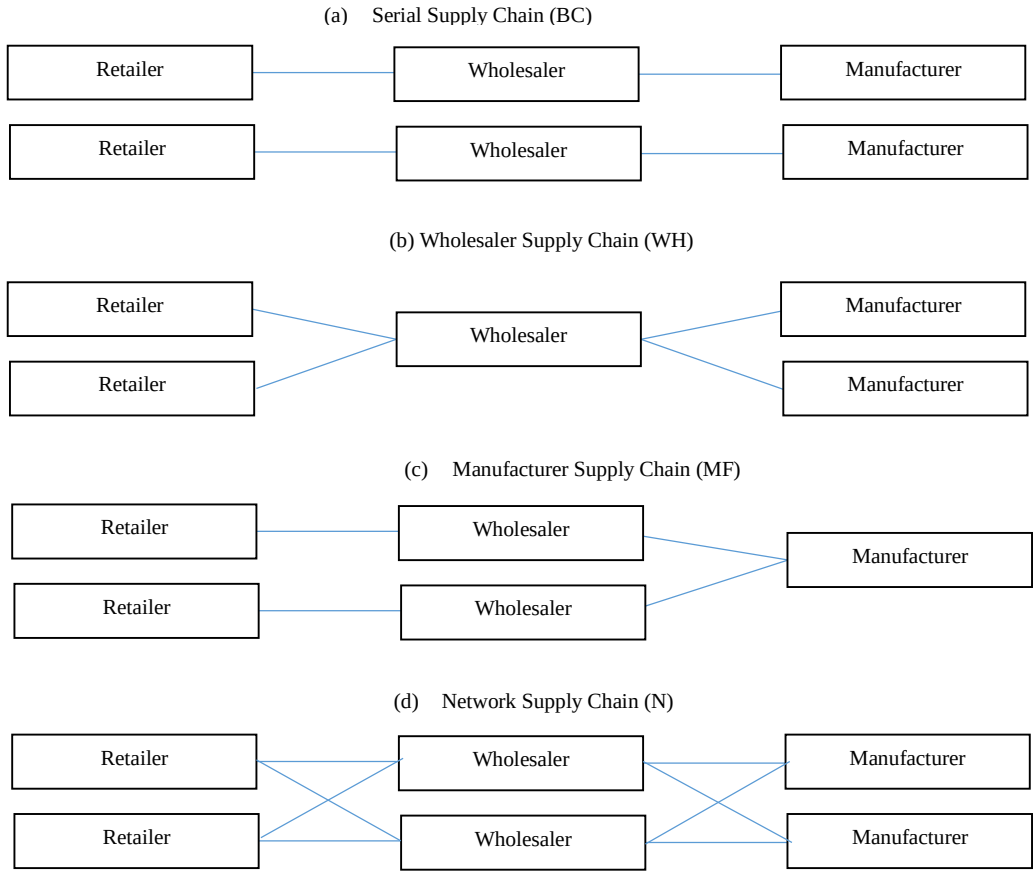


Figure 3.1 Four supply chain structures under investigation

The structures considered here represent a strategic decision which supply chains can make to improve operational performance and reduce the risk of information security breach. There are two strategies examined here: a simplification strategy and a form of risk sharing strategy called networking strategy. Figure 3.1(a) shows a typical serial structure where each supply chain agent is being served by and is serving a single upstream and downstream agent respectively. Figures 3.1 (b) and (c) is considered a form of simplification strategy where the number of agents in each tier is reduced from two to one in the serial type structure and this simplification occurs at the wholesaler tier and the manufacturer tier respectively. Therefore a wholesaler supply chain (WH) is defined as a single wholesaler serving and being served by two downstream and two upstream agents while a manufacturer supply chain (MF) is defined as a supply chain with a single manufacturer serving two different supply streams. This MF structure is somewhat equivalent to a divergent structure discussed in some literature (Lau et al., 2004) while WH structure is similar to that discussed in

(Wilding, 1998). It will be interesting to know where along the supply chain is simplification best to occur.

The last structure shown in Figure 3.1 (d) is a network structure (N) which is a risk sharing strategy (referred to in this study as networking strategy). Instead of reducing the number of agents in each tier (simplification strategy), a network is formed where multiple agents in each tier divide all the orders coming from different demand streams equally between themselves. In other words they share the risk associated with each demand stream equally between themselves. The reality of course is that in some cases, equal sharing might not be possible as some members have higher level of participation in the supply chain than others. The point being made here is that risk sharing can still take place as long as the division of responsibility to each member in the tier is commensurate with their level of participation. For simplicity and comparative reasons the number of agents in each tier has been limited to two. The interest here is to understand whether simplification strategy is better than networking strategy or vice versa.

3.3.2.2.1 The wholesaler structure model

In the WH structure, there is a single wholesaler serving two downstream retailers and two upstream manufacturers. The retailers and manufacturers in this model make their decisions independently but the wholesaler acts like a consolidation centre. After receiving the shipment from both manufacturers, the wholesaler adjusts its inventory position (eq.1-5) and an ordering decision is made depending on the ordering policy of choice. In determining its re-order point, the mean order (μ) and standard deviation (σ) used is determined from the moving average of the aggregate orders from both retailers. The order size is then split into two and sent to the two manufacturers separately. To fulfil the sum of the retailers' order (eq. 21), the wholesaler checks if its on-hand inventory is greater than the sum of the retailers' order and fulfils the entire order when the inventory level is greater (eq. 22). However when the inventory level is lesser than the sum of the orders from both retailers, then the wholesaler fulfils part of each retailer's order by sending half of the on-hand inventory to each retailer.

$$NQ_{x,t} = NQ_{x1,t} + NQ_{x2,t} \quad (21)$$

$$SS_t = \begin{cases} NQ_{x,t}, & OH_t > \sum NQ_{x,t} \\ OH_t, & OH_t \leq \sum NQ_{x,t} \end{cases} \quad (22)$$

Whatever is not fulfilled is backordered and the wholesaler maintains a record of the backlog for each retailer separately.

3.3.2.2.2 The Manufacturer structure model

For the Manufacturer structure, there exists a single manufacturer serving two separate serial demand streams. The order of activities remains the same as described in eq. (1) to (14). The only difference is that the manufacturer computes the moving average of its orders over the sum of orders from both wholesalers. Also, the order fulfilled by the manufacturer is determined in a similar way to the wholesaler in the wholesaler structure using eq. (21) and (22) and whatever is not fulfilled is backordered. The manufacturer also maintains a separate backlog record for each wholesaler when the entire order is not fulfilled.

3.3.2.2.3 The network structure model

In the network structure each agent splits its order into two and sends an order to the two upstream agents. In order words, retailer1 divides its determined order quantity into two and sends the information to wholesaler1 and wholesaler 2 separately. Retailer2 does the same and sends the orders to wholesaler1 and 2. Each wholesaler also splits its order quantity into two and sends to manufactuere1 and manufacturer2 separately. Each agent combines the order placed by downstream agent1 and 2 in determining its moving average information and the requested orders are fulfilled in a similar way described in 3.3.2.2.1 and 3.3.2.2.2.

3.3.2.3 Information Sharing Level (ISL)

The work of Lau et al. (2004) on the impact of information sharing on inventory replenishment offers a simple yet detailed information sharing model. In a similar work by Lau et al. (2002), they showed how various information sharing modes affect the dynamics of the supply chain and they presented a description of how the ordering policy is adjusted based on available information. This study adopts the conceptual model of information sharing level developed in Lau et al. (2002) and Lau et al. (2004).

Information sharing (also termed information integration or simply integration) is conceptualised in this thesis as an upstream agent privy to the demand and other

related inventory information of a downstream agent such as the inventory position, safety factor, lead time, ordering cost, backlog cost and holding cost. Information sharing level (ISL) therefore refers to where along the supply chain the information is being shared. This is a strategic decision that needs to be made carefully. Figure 3.2 shows the three main information sharing levels examined in this study. The performance of each of the three ISL strategy is evaluated against the performance of a non-information sharing mode (also called the base model). The Non-information sharing level (NI) or non-integrated mode represents a supply chain where each supply agent acts independently and do not share information with each other. Only the order information is passed from a downstream agent to the preceding upstream agent.

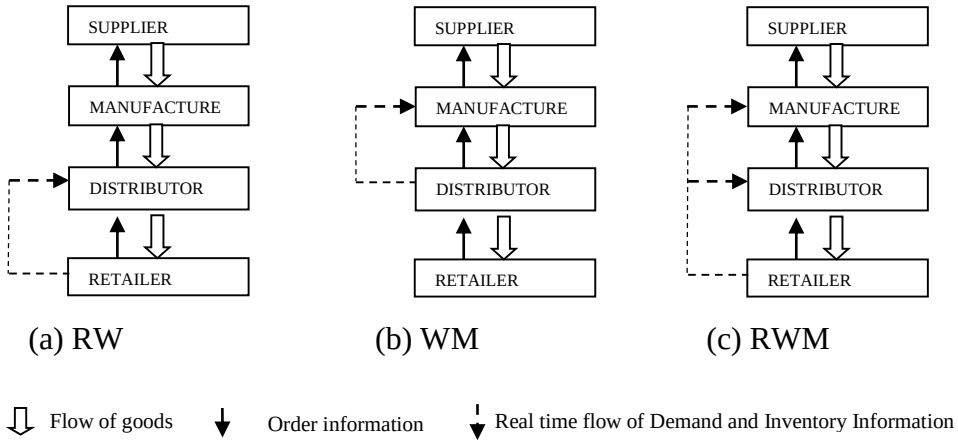


Figure 3.2 Three levels of Information sharing

3.3.2.3.1 Integration between Retailer and Wholesaler only (RW mode)

In Figure 3.2a, the RW level is a supply chain where the retailer shares market demand information and other related inventory information with the wholesaler. The wholesaler in turn uses this information in its inventory decisions. The retailer and manufacturer control their inventory as previously described but certain decision parameters changes for the wholesaler. Instead of using the installation stock, the wholesaler uses the echelon stock instead represented as IP' as shown in eq. (23). The echelon inventory position at the current period t is the sum of the inventory position of the agent calculated normally in eq. (5) and that of the retailer computed

using eq. (5) as well. The re-order point also changes to ROP′ as shown in eq. (24) while the EOQ computation changes from (18) to (25).

$$IP_t' = IP_t + IP_{x,t} \quad (23)$$

$$ROP_t' = \mu_x(L_y + L + 2) + k_x\sigma_x\sqrt{L_y + L + 2} \quad (24)$$

$$EOQ'_t = \sqrt{\frac{2\mu(f+f_x)(b+h)}{bh}} \quad (25)$$

Where μ_x and σ_x is the average market demand and standard deviation of market demand respectively instead of the retailer order since the wholesaler is now privy to this information from the retailer.

3.3.2.3.2 Integration between wholesaler and manufacturer only (WM mode)

In Figure 3.2b, the WM level represents a supply chain where the wholesaler shares its order information including other related inventory information with the manufacturer in real time. The manufacturer in turn makes its inventory decision based on the information provided by the wholesaler. In this information sharing scenario, the retailer of course does not share any information with the wholesaler and nobody is privy to market demand information except the retailer alone. Again, the decision parameters are not changed for the retailer and wholesaler but that of the manufacturer changes in a similar way to the wholesaler in the RW mode. Equations (23) and (24) applies to the manufacturer but the lead time of upstream agent (L_y) in eq. (24) changes to production lead time (PL) and eq. (25) changes to (26).

$$EOQ'_t = \sqrt{\frac{2\mu_x(p+f_x)(b_x+h_x)}{b_x h_x}} \quad (26)$$

Where μ_x is the average retailer order.

3.3.2.3.3 Integration between retailer, wholesaler and manufacturer (RWM mode)

Lastly the information sharing mode considered is the RWM mode (Figure 3.2c) which is a situation where the wholesaler and the manufacturer are privy to the retailer's market demand information and other related inventory information. The manufacturer is also privy to the wholesaler inventory information. The decision parameters of the retailer do not change but that of the wholesaler and the manufacturer changes. The wholesaler parameters is similar to those in the RW

mode and the manufacturer parameters now includes the retailer's inventory information. Therefore, the echelon stock for the manufacturer becomes the summation of the inventory position of the manufacturer calculated normally and all the downstream agent (wholesaler and retailer) as shown in eq. (27). Equations (24) and (25) also changes to (28) and (29) for the manufacturer.

$$IP'_t = IP_t + \sum IP_{x,t} \quad (27)$$

$$ROP'_t = \mu_x(L_x + L + PL + 3) + k_x\sigma_x\sqrt{L_x + L + PL + 3} \quad (28)$$

$$EOQ'_t = \sqrt{\frac{2\mu_x(p+f_x+f_r)(b_x+h_x)(b_r+h_r)}{(b_x h_x)(b_r+h_r)}} \quad (29)$$

Where μ_x and σ_x in eq. (28) represent the average and standard deviation of retailer order respectively while μ_x and subscript 'r' in eq. (29) represent the average market demand information and retailer parameter respectively.

3.4 MODELLING INFORMATION SECURITY BREACH

This study focuses on information security breach and the effect of a breach is conceptualised as a disruption in the flow of information (particularly real time market demand information). To understand breach impact, data was sourced from the 2012 information security breach survey carried out by Pricewaterhousecoopers (PwC). The data was collected and information on the average service disruption period caused by the breaches as well as the frequency of occurrence (RoC) was extracted. The extracted information was used to create profiles for each breach type and this information was incorporated into the simulation model as a deterministic model.

3.4.1 Data Collection and Analysis

The 2012 information security breach data was obtained from Chris Potter, Information Security Partner at PwC, who was involved in carrying out the survey. The survey was an online self-select survey with 447 respondent organizations and the respondents were security professionals who were in the best position to supply security related data.

The first step to appreciating security breach impact is to understand the nature of the breach occurrence. This has been tagged 'breach profiling' in this study. The data

extracted from the survey was decomposed to create the profile of each security breach type and this is shown in Table 3.2. From the table, some patterns emerged. SFDD has long disruption duration but low occurrence per year while AOW has a short disruption period but high occurring frequency. These two represent two contrasting breach types. IBMS on other hand has short disruption period like AOW but low occurrence rate like SFDD. The only difference between IBMS and PT profile is that PT has slightly higher occurrence rate. Therefore from these profiles we can begin to understand what singular impact disruption duration would have by comparing SFDD with IBMS as both have the same occurrence rate (3/yr) but differing disruption length. In the same light we can understand what singular impact occurrence rate will have by comparing AOW, IBMS and PT, particularly IBMS and PT as there is only a slight increase between these two.

Breach Type	**Average Disruption Length (days)**	**Average Occurrence/yr**
System Failure and Data Corruption (**SFDD**)	5 (Long disruption duration)	3 (Low occurrence rate)
Attack on the Web (**AOW**)	1 (Short disruption duration)	54 (High occurrence rate)
Infection by Malicious Software (**IBMS**)	1 (Short disruption duration)	3 (Low occurrence rate)
Physical Theft of Computer Equipment (**PT**)	1 (Short disruption duration)	5 (Low occurrence rate)

Table 3.2 Security Breach Profile (Extracted from ISBS 2012)

3.4.2 The Security breach model

When a security breach occurs, the information system that allows customers to place demand becomes unavailable and the breach disruption duration represents the amount of time it takes to rectify the problem caused by the breach. The assumption is that the end customer waits till the retailer's system is restored and places its demand. Therefore demand is not actually lost during the disruption period but only delayed. During this period the retailer is unable to know what the actual demand would be. The retailer then assumes the demand for that day is zero but continues to forecast demand based on moving average forecasting technique. The total amount of time the retailer is unable to see the real time demand information is equivalent to

the disruption duration of the breach. For example, SFDD has an average breach duration of 5 days which means the retailer would continue to forecast demand as usual but assumes daily demand is zero for the 5-day disruption duration. On the sixth day, however, the actual demand information plus that period's demand information becomes available creating a sort of demand increase shock for the retailer. The recurrence rate (RoC) represents the number of times this breach occur in a year. As this research is interested in understanding the reverberating effect of the breach at the retailer on the wholesaler and manufacturer cost performance, the breach is modelled to occur at the retailer's end only. Hence only market demand information is inaccessible. It is expected that an order or other inventory information can still be communicated, for example over the phone between supply agents. Consequently each breach is modelled as a delay in accessing actual demand information. It is important to state at this juncture that the cost being investigated in this study are those directly related to inventory management and not to other functions in the business such as the cost of fixing the problem or the cost to reputation or image. This is one of the scope and limitations of the research.

3.5 THE COMPUTER MODEL

The next phase of the simulation process is the conversion of the conceptual models into a computer readable model. This section is an attempt to show the application of Java Programming to the research and not a full description of what Java programming is all about. Several books and articles have presented a full description of Java programming and offered guide to using it, but the focus here is on the application of it. Several commercial software exist that have been used extensively in simulation studies. Such commercial software package as Arena, Anylogic, Automod etc., have wide application ranging from logistics, manufacturing to 3D virtual reality domain (Cimino et al. 2010). However these software packages are relatively expensive to purchase which leaves low budget users with two options: use an open source simulation programme or develop simulation models based on general purpose programming language such as Java, C, or C++. The advantage of developing the models using the general purpose language is that it affords the user the advantage of creating bespoke models for specific applications which commercial software packages or open source software may not have.

Java is a programming language that affords the user the ability to develop programmes that are concurrent, object oriented and class based. Being concurrent means codes can be run on any platform without a need for recompiling. This is because the compilation of Java applications is typically bytecode (class file) which means it can run on any Java virtual machine notwithstanding the type of computer architecture. The Java language is accompanied by a *standard class library* which is also referred to as Java Application Programming Interfaces (API) (Lewis et al. 2013). These APIs have many features, one of which is the ability to interact with databases. For this reason, and also budgetary constraints, Java programming was used to encode the conceptual model and run the simulation experiments.

All codes are written inside a class and the result of each experiment is outputted into a .txt file which is then converted into an Excel file for further analysis.

3.5.1 The Class Files

Each class file contain the description for the non-breach scenario and all the breach scenarios described in sections 3.3 and 3.4. All together each class file houses 15 separate scenarios which are the three ordering options and their respective non-breached and breached scenarios. Each scenario is run separate from the other by using a combination of `for()` and `If()` functions. Under each scenario, the variables are declared and initialised and when the simulation is complete for a particular scenario, the results are outputted into a labelled .txt file. and all the variables are re-initialised for the next scenario. Altogether there are 16 class files created for modelling the combination of the four supply chain structures and the four information sharing levels. All the scenarios created are 240 in total and the result from each scenario are converted from the .txt to the Excel file format for further analysis. Within each class, the retailer, wholesaler and manufacturer all carry out their daily activities as explained in section 3.3 and market demand is experienced and fulfilled at the end of the day at the retailer's end. A breach is modelled as a delay in the acquisition of market demand information.

3.5.2 Demand Generation

The `Math` class in Java provides a range of basic mathematical functions including random number generation function (`Math.random`). This function generates a

number in the range of 0 to 1 (1 not inclusive) and was used in selecting demand values from a normal (or Gaussian) distribution at random.

A class was created to generate random demand values from a normal distribution with mean 10 and standard deviation of 2 for each simulation day (800 in total) which is then outputted into a .txt file and labelled accordingly. Different demand streams are then generated for all 45 replication scenarios and these streams are labelled accordingly. In the computer model, the file containing the generated demand stream for the simulation is opened and the demand values are then placed in an array. At the end of each day when the retailer is expected to experience market demand, the demand value is called from the array where the demand values are stored.

3.6 SIMULATION EXPERIMENT

This study first examines the performance of the supply chain with no security breach under the various scenarios of the three strategic factors: ordering options; supply chain structures; and information sharing levels. Each strategic factor is evaluated by comparing the performance of the other alternatives to the base factor. In this study, ordering option I is considered to be the base factor for evaluating ordering option decisions. For supply chain structure, the serial structure (S) is the base factor and the non-integrated mode (NI) is the base factor for comparing information sharing alternatives. Therefore the base model for comparing all three strategic factors is the non-integrated serial supply chain structure with ordering option I. All supply chain scenarios considered in this study would have an ordering option being used, a supply chain structure and a level of information sharing. The combination of these three factors is also referred to as the supply chain condition. In other words the supply chain condition refers to the type of ordering option, supply chain structure and information sharing level present in any particular supply chain. Therefore 48 distinct supply chain conditions are considered in this study and the impact of four distinct information security breaches on these scenarios are evaluated. Therefore a total of 240 different scenarios are created and evaluated altogether as shown in Table 3.3.

	Level				
Factor	**1**	**2**	**3**	**4**	**5**
Information Security Breach	No Breach	SFDD	AOW	PT	IBMS
Ordering Options	I	II	III		
Supply chain structure	S	WH	MF	NT	
Level of Information Sharing	NI	RW	WM	RWM	

Table 3.3 Design of Experimental Scenarios

The values of the simulation parameters for the experiment are shown in Table 3.4. These values are derived from Lau et al. (2002 and 2004). The market demand is observed at the end of the day and is normally distributed with mean of 10 and a standard deviation of 2. The capacity of the manufacturer is 80 and the production lead time is 3 days. The assumption is that manufacturer capacity is in use for the duration of the production lead time after which it becomes available again, an assumption also used in Lau et al. (2004). For instance if the manufacturer is committed to producing 80 items at once, then 80 units of capacity is unavailable for 3 days and any more production orders will have to wait until the production lead time is completed.

Each experiment was run for a total of 800 simulation days and, using time series inspection method, the warm up period was determined to be 100 days leaving an effective simulation period of 701 days. Using the confidence interval method described in Law (2007), the number of replication was determined to be 45 at 98% confidence level and the same random number streams were used for each experiment to ensure consistency and variance reduction (i.e. reduce randomness effect) (Kelton et al., 2010).

Parameter	Value
Demand (units)	NORM(10,2)
Demand Arrival	End of day
Production Lead Time	3 days
Manufacturer Capacity	80
Transportation Lead time from Wholesaler to Retailer	2 days
Transportation Lead time from Manufacturer to Wholesaler	5 days
Retailer Unit Holding cost, Backlog cost, Ordering cost	£5, 10, 5
Wholesaler Unit Holding cost, Backlog cost, Ordering cost	£3, 10, 5
Manufacturer Unit Holding cost, Backlog cost, Production cost	£3, 10, 5

Table 3.4 Simulation parameters

3.6.1 Performance Measures and Test of Significance

The cost performance measures used in this study include the holding, backlog and ordering cost (similar to Lau et al. 2002), while the service performance measure used is the fill rate (commonly used in many studies). The performance measures are averaged over the effective simulation period and this is computed for each supply agent (the retailer, wholesaler and manufacturer) and the sum of the three cost is referred to as the daily average operating cost. The sum of the daily average operating cost of all three agents is called the supply chain daily average operating cost. The fill rate is only considered at the operating level of each supply chain agent but not considered as a performance measure for the supply chain as a whole. The average performance under security breach in each scenario is noted and the difference in performance level to that of the corresponding non-breach scenario is called the breach impact. This impact is expressed as a percentage of the non-breach scenario performance.

To test for significance during result comparison, we employed the Paired-t Confidence Intervals for Mean Differences with Bonferroni Correction and standard-t Confidence Intervals for Mean Differences with Bonferroni Correction at 95% confidence level (Law, 2007, Robinson, 2004). It is important to note that while the difference between two values may be statistically significant, it does not mean the

magnitude of the difference is a huge concern. To help understand the impact of information security breach on supply chain performance, the effect of each breach on the ordering pattern of the agents in the supply chain is examined. The ordering pattern is defined by the frequency of placing an order to the upstream agent and the effective average order quantity computed over the ordering days only. In addition the singular effect of both element of the breach profile (i.e. disruption duration and recurrence rate) is studied to understand how increasing one element affect the magnitude and direction (whether positive or negative) of breach impact. Then the effect of changing the strategic factors from the base model to the other alternatives is examined to determine if any improvement can be obtained. An improvement in performance (which should also be statistically significant at $p<0.05$) would show that the alternative strategic factor also holds benefit in a breach scenario.

3.6.2 Sensitivity Analysis

Sensitivity analysis, also known as what-if analysis, is a systematic investigation of the reaction of the model output to changes in model input and or model structure (Kleijnen, 1995). The demand input constitute the only random input in this model and since a breach is modelled as a delay and not loss of demand information, the demand stream used represents the single most important source of uncertainty. The question asked here is; if the variability of the demand stream is increased by two fold, what happens to the findings? Does the impact of information security breach increase or decrease? And is this change consistent or inconsistent for all supply chain scenarios. The assumption in this study is that demand follows a normal distribution with mean of 10 and a standard deviation of 2. Therefore to accept that the findings in this study are true for any stream of demand, the standard deviation of the demand distribution was increased from 2 (low) to 4 (high) to perform a sensitivity assessment of the main model (base model) in this study. The result of the effect of increasing the standard deviation of the demand distribution from 2 to 4 is shown in Table 3.5.

	Option I	Option II	Option III
NB	-6%	-17%	-17%
AOW	-15%	-14%	-15%
IBMS	-8%	-16%	-18%
PT	-9%	-16%	-18%
SFDD	-12%	-5%	-12%

Table 3.5 Effect of increased variability in the demand distribution

The values were obtained by computing the difference between the cost performance under low demand variance (2 standard deviation) and high demand variance (standard deviation of 4), expressed as a percentage of the former. A negative sign indicates the supply chain daily average operating cost in the high demand variance scenario is higher than the low demand variance scenario. Although one would expect that a change in the variability of the demand distribution would affect the performance of the supply chain as the result reveals, however the consistency in the result is of concern here. It can be seen from the result in Table 3.5 that increasing the demand variance consistently increases the magnitude of the impact but not the direction of the impact for both breach and non-breach scenarios. The consistency in the direction of the effect implies that for all 15 scenarios, the observed effect is an increase in cost performance and not an increase in some and then a decrease in others. Hence the inference drawn from the output of this study using low demand variance (standard deviation of 2) is expected to be consistent for any demand stream following a normal distribution regardless of the demand variance.

In a broader sense, the effect of changing the different aspects of the supply chain (ordering option, structure and information sharing level) from one alternative to another using the design of experiment described in section 3.6 is also a sensitivity analysis in itself.

3.7 VALIDATION AND VERIFICATION

In simulation modelling, the models developed and used in mimicking real life systems or problems need to be verified and validated. Model verification and validation needs to be conducted throughout the modelling phase and the experimental phase of simulation. According to Sargent (2010 p. 166), model

verification is defined as “ensuring that the computer program of the computerized model and its implementation are correct” while Cimino et al. (2010 p. 6) adopted the following definition for model validation; “the process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended use of the model”. The conceptual model, which is a mathematical and/or logical model has to be an accurate representation of the real system being studied, hence validation is done at this stage to ensure this. Once this is done, the computerisation aspect of the modelling process has to be verified to assure that the conversion of the conceptual model into a computer model and its implementation is correct (Sargent 2010). Lastly, during the experimentation phase the output of the simulation experiment has to be validated as well to ensure the result exist within an acceptable range of accuracy and to assure the decision maker or users of the information of the correctness of the model for the intended use. These validation and verification needs to be done to assure the integrity and credibility of the simulation model in addressing the objective of the real life system. One commonly used method for validation is comparison with other models that have been validated in literature.

3.7.1 Conceptual Model Validation

The conceptual model used this study has already been validated by previous work in literature. Several authors have used the same representation of the three ordering policies used in this study. Option I has been used by Cimino et al. (2010), Chatfield et al. (2004), and (Agrawal et al., 2009, Bensoussan et al., 2007, Beamon and Chen, 2001, Chen et al., 2000). Option II was developed by (Axsäter, 1996) and option III has been used by Lau et al. (2002). The mathematical representation of the levels of integration used in this study was developed and validated by Lau et al. (2002) and Lau et al. (2004). Validating the conceptualisation of the supply chain structure is rather simple. The three supply chain structures are simplification (WH and MF) and networking strategies (NT) being considered as an alternative to the serial type structure. The structures are merely a reduction in the number of agents within a tier or simply a splitting of orders coming from downstream agents. Reducing the number of agents in each tier translate into a single agent (wholesaler in WH structure or manufacturer in MF structure) aggregating and fulfilling the orders from downstream agents. These type of structures have been studied in the past, however,

under different circumstances. The splitting of order is conceptualised in this study as equal sharing between agents in the same tier. While it is possible that equal splitting may not be agreed to by members in many supply chains, the point is that the proportion of split can be made based on the size and level of commitment of the supply agents. In this study, the assumption is that all supply agents are of equal size and the level of commitment to the chain is the same, which is the case for many supply chains.

The supply chain parameters and assumptions used in this study are similar to the ones used in Lau et al (2002) and Lau et al. (2004) and the result of the study is used to validate the output in this study. Here is a summary of all the main assumptions made in the supply chain

- Demand is normally distributed with mean of 10 quantities and a standard deviation of 2
- All the lead times are constant.
- All members of the supply chain use the same ordering policy
- If on-order quantity cannot be met with current on hand inventory, then the on-hand inventory is shipped and the rest is back ordered leaving the agent with zero inventories.
- Each unfulfilled order is backordered and a shortage or back log cost is incurred per unit item including a fixed shortage cost once an order is unfilled or partly filled
- The performance of each tier is seen as an average of the performance of all the agents within that tier.
- Agents in the same echelon use the same sharing mode.
- The total production capacity at the manufacturer tier is equal to 80 equally split between all manufacturers.
- A unit of production capacity makes a unit of the product for the duration of the production lead time.
- The manufacturer has an unlimited and unfettered supply of raw materials.

3.7.2 Computer Model Verification

The programmed model is verified to ensure the implementation of the codes is correct. The Java Development Kit (JDK) includes development tools such as Java

compiler, Javadoc, Jar and a debugger. The debugger is an excellent tool that aids the user in determining programming errors which might affect the output or running of the simulation model. In other words it is a useful verification tool (Kleijnen 1995) that helps to ensure (in part) the integrity of the written programme. Each time there is an error in coding, the java compiler registers an error and the programme will not be executed until the error is found and fixed. On the other hand, a very useful and widely used verification method is structured walkthrough or traces. According to Sargent (2010) traces is defined as following (tracing) the behaviours of different types of specific entities through the model to determine if the model's logic is correct and if the necessary accuracy is obtained. In this study, each of the 240 scenarios is run for a simulation time of 10 days and the predicted result (obtained by manual calculation) is compared with the simulation output. This confirmed that the computerised model was properly implemented using the java programming language.

3.7.3 Experimental Output Validation

Experimental output validation is also known as operational validation. The aim is to check if the output of the computerised model exists within the level of accuracy required for the model's intended purpose over the domain of the model's intended applicability. To ensure this accuracy, during the experimentation phase the simulation warm up period was determined and the output was computed over the effective simulation period which is the total simulation time minus the warm-up period. This was done to remove the warm-up effect and ensure that the output was determined over a steady state. In addition, a confidence level (98%) was built into the result by conducting multiple replications (predetermined to be 45) for each of the 240 scenarios (making the total number of experiments 10800). The output for each scenario was averaged over the 45 replications meaning the result was computed with 98% confidence.

3.8 ENTROPY ANALYSIS

Entropy, in information theory, is a measure of the uncertainty associated with a random variable. If there are several possible events that may occur and the probability of occurrence of each event is known, there exists a conundrum of determining how much "choice" is there in the selection or how uncertain one would

be of the outcome (Shannon 1948). This "choice" or uncertainty conundrum can be measured using Entropy Theory.

3.8.1 Shannon's Entropy

The mathematical definition of entropy as prescribed by Shannon (1948) is a quantitative measure of uncertainty (Martínez-Olvera, 2008, Sivadasan et al., , 2002) and this is shown in equation (30):

$$H(S) = -\sum_{i=1}^{n} p_i \log_2 p_i \qquad (30)$$

H(*S*) is the entropy level of the system, defined here as the expected amount of information needed to describe the state of the system *S* , and p_i is the probability of an event *i* (*i*=1,....,*n*) occurring, where $p_i \geq 0$ and $\sum_{i=1}^{n} p_i = 1$

If the probability of each event occurrence within the system, S, are equal, then there is more choice (or higher uncertainty) when the number of events, *n*, increases. This means that $p_i = 1/n$ and *H(S)* would be a monotonic function of *n*, and is considered to be the **maximum entropy** of the system. However if a choice (that is one of the possible events) can be decomposed into two successive sub-events, then it follows that the total entropy would be a weighted sum of the individual entropy values. For instance if the system has possibility of two events *a* or *b* occurring, and b can be decomposed into events b_1 and b_2, according to Shannon:

$$H(a, b_1, b_2) = H(a, b) + bH\left(\frac{b_1}{b}, \frac{b_2}{b}\right) \qquad (31)$$

It generally follows that if '*a'* is the chance/probability that an event will occur and '*b*' is the possibility that that event will not occur (i.e. b =1-a) then the first expression in eq. (31) becomes:

$$H(a, b) = -(a log_2 a + b log_2 b) \qquad (32)$$

It also follows that since '*b*' may occur over several states, b_1, b_2, b_3 *...n* then the second expression in eq. (31) can be rewritten as:

$$bH\left(\frac{b_1}{b}, \frac{b_2}{b} \ldots \frac{b_n}{b}\right) = -b(\sum_{i=1}^{n} b_i^* \, log_2 b_i^*) \qquad (33)$$

Where $b_i^* = \frac{b_1}{b}, \frac{b_2}{b}, \ldots \frac{b_n}{b}$

Therefore the sum of eq. (32) and (33) represents the total entropy (hence the level of uncertainty) of the system experiencing an event that has a probability of occurrence '*a*' (with probability of non-occurrence *1-a = b*) with the non-occurrence probability existing within several countable space (b_1, b_2, b_3 ...n). These two equations were later adapted by Sivadasan et al 2002 and they called eq. (32) operational complexity index (OCI) S^{INC} and eq. (33) they called OCI S^{NC}. These two equations were used as a measurement of complexity which derives from variation in information and material flow between a supplier and a customer. They obtained data from two organizations and measured the variation between sales forecast and sales order; sales order and actual dispatch; purchasing forecast and purchasing orders; purchasing orders and actual deliveries. These variations were sources of uncertainty which result in operational complexities that can be passed on from one business to the other (Sivadasan et al. (2002). Frizelle and Efstathiou (2002) explained that high entropy can impede flow by introducing obstacles that makes supply chain operations less predictable. By inference, disruption in information flow introduces obstacles to the flow of operation and the predictability of these disruptions can help evaluate the level of chaos they introduce into the system. The argument is that since information security breach can be modelled as a disruption in the flow of real time market demand information, the level of entropy introduced into the operation can be determined once the probability space of disruption occurrence is known.

Therefore uncertainty can be defined and measured as the deviation from a scheduled or planned state which in this study is conceptualised as the performance deviation of a breached state from a non-breach state. The approach is to evaluate disruption threats using established threat occurrence to work out the level of entropy each threat introduces into the system.

3.8.2 Applying Shannon's Entropy to Information Security Impact Assessment

In this study both equation (32) and (33) were adapted where '*a'* would be the probability of a breach not having a negative impact while b is the probability of the breach having a negative impact. This negative impact can occur over several countable states, which is explained in the following section. The expression in eq. (32) is called the "Nature Uncertainty" and that in eq. (33) is tagged the "Extent Uncertainty". The term uncertainty is used interchangeably with entropy through the

text. This entropy assessment will help identify those threats that are hot spots to guide management decision in selecting appropriate strategy that mitigates the impact of information security breach.

3.8.2.1 Nature Uncertainty

The uncertainty associated with knowing whether the system is "in-control" or "not-in-control" is called the nature uncertainty (NU). The in-control state is conceptualised as the information security breach not having a negative impact on the performance of the supply chain, while a not-in-control state is defined as a breach having a negative impact on supply chain performance. Adapting the concept in this study, eq. (32) becomes eq. (34), where P is the probability that a breach will exist within the in-control state.

$$H\ (\text{NU}) = \ -P\log_2 P - (1-P)\log_2(1-P) \qquad (34)$$

H (NU) is the uncertainty associated with not knowing whether there would be a negative impact or not, that is the 50/50 chance of a negative impact. The closer the probability (P) of in-control (i.e. no negative impact observed) is to 50%, the closer NU is to the maximum value, 1. Also the further the probability of in-control is from 50% either increasing or decreasing, the closer NU is to 0. Hence the lower the NU score the more certain you are of either experiencing a negative impact or not, the higher the score the less certain you are.

3.8.2.2 Extent Uncertainty

The second expression of uncertainty is the extent uncertainty (EU) which is the uncertainty associated with the existence of the system in several not-in-control states. In other words, EU is the uncertainty of knowing the number of countable states the negative impact can occur in, given that the system is not-in-control. This is shown in equation (35), where p_i* is the conditional probability computed over the "not in control" state with states i (i=1,..., n).

$$H(EU) = -(1-P)(\sum_{i=1}^{n} p_i^* \, log_2 p_i^*) \qquad (35)$$

This index is a measure of the amount of information needed to monitor the extent to which the system is not in control i.e. the extent of negative impact. Higher scores occur when the impact is spread over several countable states, and lesser scores occur over fewer countable states. Consequently the higher the probability of

experiencing a negative impact over just one single state or non at all, the closer EU is to 0. NU cannot exceed 1 but EU can exceed 1 depending on the spread of impact.

3.8.2.3 Total Uncertainty

The total uncertainty or entropy (TE) is the sum of nature uncertainty and extent uncertainty and this is used in this study's assessment. It follows that the higher the TE, the higher the uncertainty introduced by the breach into the system and hence the more the associated information needed to manage the system and vice versa. The concept of Entropy has been adapted in this study to reflect the level of uncertainty created by disruptive threat in a supply chain.

3.8.3 The Entropy Assessment Methodology

Simulation approach allows the user to develop a computerised version of the real system in order to investigate the impact of certain variables on the system which may be difficult to assess in real life. The computerised version is then run under different scenarios (experimentation). The output of each scenario is usually averaged over a number of replication, predetermined to ensure that the output falls within certain level of confidence. In other words the mean output is a mean aggregate of the output of each replication. Consequently the output of each replication is important in determining mean output of a particular system. It stands to reason that the uncertainty associated with the state of a system (in this case the mean output) is a function of the uncertainty associated with the member states of that system (in this case output of each replication). In this study the performance of the supply chain under a breach scenario is under study and for a 98% confidence level in the result, the simulation had to be conducted with 45 replications. In other words 45 different demand scenarios were created and the impact of the breach was determined to be the average of all 45 scenarios. In the entropy analysis, each of the 45 demand scenarios were used and the steps are outlined below with Table 3.6 representing an illustration of the computation using the manufacturer's average backlog performance as an example:

Replication	Difference in quantity (n-BS minus BS)	Replication	Difference in quantity (n-BS minus BS)	Bin	Frequency (*f*)
1	0	24	0	10	0
2	0	25	0	8	0
3	0	26	0	6	0
4	1	27	0	4	0
5	0	28	0	2	8
6	1	29	0	0	37
7	0	30	0	-2	0
8	0	31	1	-4	0
9	0	32	0	-6	0
10	0	33	1	-8	0
11	0	34	0	-10	0
12	0	35	0	-12	0
13	0	36	1	-14	0
14	0	37	0	-16	0
15	0	38	0	-18	0
16	0	39	0	-20	0
17	**0**	40	0	-22	0
18	0	41	1		
19	1	42	0		
20	0	43	1		
21	0	44	0		
22	0	45	1		
23	0				

Table 3.6 The Manufacturer average backlog performance example

a) Determine Breach Impact

From the experimental result, the impact of a breach on each supply chain performance indices, average backlog quantity and on-hand inventory, is first established for each supply chain member/agent by computing the difference between the operational performance of each agent in the non-breach scenario (i.e.

system under control) and that in the corresponding breach scenario (i.e. system not-in-control). The performance measure used here is the quantity measure instead of the cost measure to enhance the generalisability of the finding. For instance the impact on average backlog quantity was used instead of average backlog cost. Comparison is between same agent in both scenarios i.e. manufacturer in the breach scenario (BS) and manufacturer in the non-breach scenario (n-BS). The breach impact is construed as the daily average performance measure of an agent in the non-breach scenario minus that in the breach scenario. A positive difference indicates there is reduction in average quantity when breach occurs and negative indicates there is increase in average quantity when breach occurs. This information for the manufacturer's daily average backlog quantity can be found in column two of Table 3.6. Only the average backlog quantity and on-hand inventory is used in this analysis. The average ordering quantity is not included in this analysis as the impact of information security breach on it is not large enough to warrant such analysis.

b) Determine the Countable States of Negative Impact

Once the impact of the breach under each replication is determined, the difference is categorised into bins (which is also referred to as states). According to Sivadasan et al. (2002), these states must be carefully selected and should represent a significant variation from one state to another. Therefore this study conceived that since the average daily demand follows a normal distribution with an acceptable standard deviation (SD) of 2, any deviation above 2 would amount to an aberration which upsets the system. Consequently, the states are determined to be in increment of 2. Simply put, the standard deviation modelled into the demand distribution is used as the state differentiator. Therefore each bin is an increment of 2 quantities. This is shown in the fifth column of Table 3.6.

c) Determine the frequency of occurrence of each state

After creating the bin states, the number of replications whose quantity difference exist within each state is counted and written down. Since risk assessment is generally based on the negative impact of threat, all states in the positive range is considered to be an in-control state and all negative states are considered to be not-in-control state.

d) Compute the probability of in-control and not-in-control

The total number of replications existing within the in-control state is determined and divided by the total number of replications. Using the example in Table 3.6;

No. of In-control replications (N_{IC}) = 45

No. of Not-in-control replications (N_{NIC}) = 0

Probability of In-control, $P(N_{IC})$ = NIC/Total No. of Replication = 45/45= 1

Probability of Not-in-control, $P(N_{NIC})$ = 1-Probability of In-control= 1-1= 0

Probability of state i, $p_i = f(i)$/ Total No. of Replication

Where *f(i)* is the number of replications existing within state i

and i = (10,8,6,4,2,0,-2,-4,-6,-8,-10)

e) Compute *H(NU)* and *H(EU)*

Applying eq. (34) to the example yields *H(NU)*= 0 indicating that the uncertainty of knowing whether the breach impact on manufacturer's daily average backlog performance will be negative or positive is nil. Consequently, one is more certain that future breach impact will not be negative under similar supply chain condition.

The computation for *H(EU)* using eq. (35) also yielded zero. Since no negative state was found, it suffice to say that the uncertainty associated with knowing the extent of negative impact is zero which means one is quite certain that the extent of negative impact of future breach occurrence of that specific breach type will be zero since no negative impact was found in all 45 scenarios.

The total entropy (TE) of the system is *H(NU)* + *H(EU)* = 0, which implies that little or no amount of information is needed to control the outcome of the impact of this particular breach on manufacturer's daily average backlog performance in the future, provided the breach type exist within the current breach profile. However it is important to note that the profile of information security breach may change as the level of sophistication of perpetration increases, and this might affect the dynamics of its impact. Therefore this sort of analysis should be done regularly to see if the profile has changed and if the information needed to control the impact should be increased.

This analysis was carried out for each performance measure (in terms of average daily quantity) for each supply chain agent and the aggregate of the total entropy for each supply chain agent was computed to give the supply chain total entropy level.

3.8.4 Determining the Maximum Number of States

From past literature, it is known that maximum entropy occurs when the probability of each state (*i*) are the same over the number of states, *n*, (Shannon 1948). Therefore, entropy is a monotonic function of *n* such that $H(EU) = \log_2 n$ is the maximum entropy. The following condition therefore applies:

$$0 \leq H(EU) \leq \log_2 n$$

On the other hand the maximum of *H(NU)* is 1 as it a classical example of entropy with two equal possibilities (Shannon 1948).

Consequently the maximum total entropy is $TE = \max\ H(NU) + \max H(EU)$ and the following condition applies: $0 \leq TE \leq 1 + \log_2 n$

It is important to note here that the larger the *n*, the greater the maximum entropy, therefore *n* should be chosen within reason. For some systems, determining *n* is quite straightforward. For example, the outcome of throwing a pair of dice may take one of 36 possible combinations. The number of states is straight forward in this example, 36 states. However, for others it may require well informed subjective judgement or case specific information. It is particularly difficult for security impact studies as the profile of a breach may become worse than anticipated and as such create a very wide difference which may not be covered within the predetermined states. For instance if the maximum state for the negative impact is predefined as between -10 and -12 (i.e. max *n*=5) and, due to an increase in the level of sophistication, the same breach at a future date creates a surprise increase in performance quantity of 15, then maximum *n* would need to be recalculated based on this new possibility. Finding the generic or universal *n* is beyond the scope of this study, but is determined within reason based on the output of the simulation experiments. The author agrees with the following statement given by Carter (2011):

"*We shouldn't expect to be able to come up with a single universal measure of complexity. The best we are likely to have is a measuring system useful by a particular observer, in a particular context, for a particular purpose."*

Therefore maximum *n* was selected after all replications of the different 192 breach scenarios had been carried out. The replication showing the largest variation in performance quantity was used to set max *n*= 11 and the size of the variation was 21. This was done to preserve the generalisability of the analysis for all security breach considered in this study. It is therefore admitted that while the severity of information security breach may significantly increase over the years, each assessor must revisit the decision for *n* and find one that is most suited for the current situation.

Recall that the higher the total entropy the more information is needed to manage or control future breach occurrence. High entropy systems require more information than low entropy systems. However for managers, this analysis should be able to inform the decision of what to do if entropy is high or low or even medium. A classification system would be useful to help managers decide what the "appropriate action" to take given their uncertainty status. "Action" in this context would be to either increase or decrease their monitoring and control effort for each breach type and corresponding inventory management operations, while the term "appropriate" in this context means 'to what monitoring and control level'?

3.8.5 Entropy Categorisation

If a small proportion of the total number of replication outputs a negative breach impact (i.e. not-in-control), then the possibilities or choices are less in comparison to when the proportion of not-in-control are greater. It is therefore necessary to create a classification of the range of choices to help practitioners determine if any actions are needed and to what extent the action needs to be carried out. Let *x* be the number of replications that are in control when a breach occurs (i.e. no negative breach impact occurred) and let *y* be number of replications that are in the not-in-control state (i.e. negative impact occurred), $y = 45\text{-}x$. It follows that there are 46 different combinations of (*x*,*y*) that may occur as shown in Table 3.7. Each combination is referred to as an outcome. C1 represents the outcome where all of the 45 replications do not output a negative breach impact while C46 represents the outcome where all 45 replications output a negative breach impact. Due to the fact that *y* may occur in any of the 11 states that was already predetermined, the maximum $TE_{n=11}$ was determined for each combination and the result is shown in Table 3.7. Therefore the

maximum entropy that any of the 46 combinations can attain, given that n=11, is 3.57 represented by combinations C42 and C43.

	Possible Outcomes									
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
x	45	44	43	42	41	40	39	38	37	36
y	0	1	2	3	4	5	6	7	8	9
Max TE	0.00	0.15	0.31	0.46	0.61	0.76	0.91	1.06	1.21	1.36
	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20
x	35	34	33	32	31	30	29	28	27	26
y	10	11	12	13	14	15	16	17	18	19
Max TE	1.50	1.65	1.75	1.85	1.95	2.04	2.14	2.23	2.33	2.42
	C21	C22	C23	C24	C25	C26	C27	C28	C29	C30
x	25	24	23	22	21	20	19	18	17	16
y	20	21	22	23	24	25	26	27	28	29
Max TE	2.51	2.60	2.69	2.76	2.83	2.90	2.96	3.03	3.09	3.15
	C31	C32	C33	C34	C35	C36	C37	C38	C39	C40
x	15	14	13	12	11	10	9	8	7	6
y	30	31	32	33	34	35	36	37	38	39
Max TE	3.21	3.27	3.32	3.37	3.41	3.45	3.48	3.51	3.53	3.55
	C41	C42	C43	C44	C45	C46				
x	5	4	3	2	1	0				
y	40	41	42	43	44	45				
Max TE	3.57	3.57	3.57	3.56	3.54	3.46				

Table 3.7 The maximum entropy of each possible outcome

It is clear from the result that max *TE* increases as *y* increases or as *x* decreases. Consequently the classification of the amount of choice present is done using y (the

number of replications outputting a negative impact or simply not-in-control state) and the corresponding entropy categorisation is done using the maximum *TE* values.

Ideally one would prefer that the impact of information security breach on daily average performance should be minimal. In other words the negative impact (i.e. variation of the average on-hand inventory or backlog quantity) should not be more than one standard deviation (SD = 2 in this case). This means that the variation should exist within only one state (n=1). A variation of 2SD (which equals 4 units) would be considered a low impact and this means any negative impact may span over two countable states (i.e. n=2). A variation of 3SD is considered moderate or medium impact (with spread over 3 states, n=3) and above 4SD is considered high (with n=4) Therefore total entropy values existing within the Max TE values when n=1 is considered nil; n=2 is considered low; and n= 3 is considered medium and n ≥ 4 is categorised as high. From the maximum entropy estimation for this study over these states, the categories of uncertainty level is classified as follows:

	Level of Uncertainty		
	Low	Medium	High
Total Entropy values	0.01 - 1.00	1.01 - 1.59	1.6-3.57
Rating	1	2	3

To obtain the uncertainty level for each supply agent, the mean of the rating of the average on-hand inventory and average backlog quantity for each agent is computed, rounded to the nearest whole number. The corresponding uncertainty rating for each agent is classified as low, medium and high as explained above. This classification and rating is done for all the 192 supply chain scenarios.

3.9 SUMMARY OF STUDY APPROACH

In practice, several alternatives of a specific strategic factor exist and some alternatives give better operational benefit than others. It is therefore worthwhile for supply chains to consider adopting the more promising alternative. However because a particular alternative offers benefit in one supply chain does not necessarily mean it holds benefit in another. Again, the purported benefit may however be short lived when the information system used to leverage business activities is compromised by

information security breach. Therefore an investigation of whether it would be suitable to one's supply chain is required, especially in the event of a security breach. Therefore this study aims to understand, the effect of changing from one alternative strategy to another and the effect of making more than one strategic decision. This effect is investigated under a breach and non-breach scenario to understand whether the effect of a particular strategic factor (or combination of factors) exacerbates or mitigates the impact of information security breach on supply chain inventory management performance.

Simulation modelling is a cost effective approach of investigating the effect of various factors and alternatives on supply chain performance. Its application has to be carefully considered to ensure it is an accurate representation of the real system. To achieve this, verification and validation is required throughout the life cycle of the simulation model. Simulation modelling is accomplished by developing conceptual models of the real system or problem entity, which is then converted into computer models in order to perform different experiments on the said model. The output of the simulation experiments is then analysed and inferences can be drawn.

The output of the breach scenario is compared to the output of the non-breach counterpart, and the ensuing percentage difference is termed breach impact. This breach impact is a direct cost impact assessment.

Apart from the direct cost impact information security breach has on the supply chain inventory management performance, these breaches also introduce uncertainties in the supply chain. These uncertainties make it difficult to ascertain what future breach impact would be on the supply chain and hence might affect future performance of the supply chain. Due to the uncertainties associated with information security breach impact the supply chain decision of which alternative strategy to adopt should not be made on only direct cost impact alone. Although some alternative strategies may offer benefit to the supply chain, it is not clear how the uncertainty level of the breach increases or decreases in the new structure. This study posits that any change in breach impact uncertainty level will produce a corresponding change in the level of monitoring and review required in the supply chain and this has cost implication. It is therefore imperative that the decision to change from one alternative to another should not only be based on direct impact

cost assessment but also on the indirect cost implication that changing uncertainty level represent. This study therefore incorporates the uncertainties of breach impact in making a final decision.

The entropy assessment described in section 3.8 above is one of the contributions of this study. While entropy has been used as an assessment tool in certain studies (Sivadasan et al. 2002; Martinez-Olvera 2008; Airoldi et al. 2011), this entropy assessment methodology is novel in its application to information security impact studies. The framework thus developed (explained in Chapter 6) demonstrates that using a direct cost impact assessment could be misleading and it is imperative to also include an indirect cost impact assessment to get a complete picture. This would help supply chain managers make the right strategic decisions that are robust both in non-breach and breached situations.

Chapter 4 INFLUENCE OF INFORMATION INTEGRATION AND SUPPLY STRUCTURE ON SUPPLY CHAIN PERFORMANCE IN A NON-BREACH SCENARIO

4.1 INTRODUCTION

Several studies have examined the role of information sharing on supply chain performance. Other studies have looked at the performance of the supply chain under varying levels of information sharing (Chan and Chan, 2009, Yang et al., 2011, Lau et al., 2002, Lau et al., 2004) but this has largely been based on one ordering policy. It is however difficult to ascertain the relative performance of different ordering policies under various information sharing levels from past studies because each study was based on different supply chain conditions. A study where the various ordering policies are compared to one another under various information sharing scenarios would provide a more substantive means of comparison. Therefore each ordering policy has to be subject to the same supply chain conditions to obtain any meaningful comparison.

This study goes even a step further and examines this performance under various supply chain structures. Certain structures by themselves gives operational advantage to certain supply chain members and when this is combined with information sharing, the resultant effect to supply chain members may be positive or negative. Some have looked at structure separately (Beamon and Chen, 2001, Mills, 2004, Xu et al., 2010) and others information sharing separately (Bourland et al., 1996, Lau et al., 2002, Lau et al., 2004). It has not been specifically established in past studies how supply chain structure interacts with information sharing. This study aims to fill that gap. It is important for supply chain members to know how their operation will be affected in any information sharing scenario so that proper incentives can be put in place to foster existing or newly formed partnerships.

4.1.1 Brief Description of the Three Strategic Factors and Their Alternatives

Information sharing (also termed information integration or simply integration in this thesis) is conceptualised as an upstream agent privy to the demand and other related inventory information of a downstream agent such as the inventory position, safety factor, lead time, ordering cost, backlog cost and holding cost. Information sharing level (ISL) therefore refers to where along the supply chain the information is being

shared. The Non-information sharing level (NI) or non-integrated mode represents a supply chain where each supply agent acts independently and does not share information. The RW level is a supply chain where the retailer shares market demand information and other related inventory information with the wholesaler. The wholesaler in turn uses this information in its inventory decisions. The WM level represents a supply chain where the wholesaler shares its order information including other related inventory information with the manufacturer in real time. The manufacturer in turn makes its inventory decision based on the information provided by the wholesaler. In this information sharing scenario, the retailer of course does not share any information with the wholesaler. Lastly the information sharing mode considered is the RWM mode which is a situation where the wholesaler and the manufacturer are privy to the retailer's market demand information and other related inventory information. The manufacturer is also privy to the wholesaler inventory information.

The supply chain structure has been defined in this study as a reflection of a singular organisation, be it wholesaler or manufacturer, serving more than one upstream and/or downstream agent as explained earlier in section 3.3.2.2. The first structure, also considered the base structure, is a serial structure where each supply chain agent is being served by and is serving a single upstream and downstream agent respectively. The wholesaler (WH) and manufacturer (MF) structures are considered to be a form of simplification at the wholesaler tier and the manufacturer tier respectively. The last structure considered in this study is a network structure (NT) which is a risk sharing strategy (also called networking strategy) that entails a supply chain with multiple agents in each tier of the supply chain serving and being served by two supply agents.

This study compares three different ordering policies (also called ordering options) under the same supply chain conditions. Option I is the base stock policy, which is a parameter based policy where the order quantity is determined by the difference between two decision parameters (inventory position and order-up-to level). Option II is the optimal stochastic EOQ model which is a form of batch ordering policy where the order quantity is not determined by the difference between two decision parameters but computed separately when a decision point is reached (i.e. when inventory position falls below re-order point). Option III is a combination of the

other two, and it is a modified base stock policy with an additional element called a simple non-optimal stochastic EOQ component. The order quantities generated by the three policies are not fixed but variable in nature and have been discussed in greater details in Chapter three. This sort of comparison based on a combination of different ordering policies, supply chain structures plus the extent of information sharing is missing in literature and this study fills that gap.

4.1.2 Research Motivation and Questions

This study is important so as to create a more holistic understanding to information sharing benefit. The effect of supply chain structure coupled with the extent of information sharing is expected to be different in magnitude as well as direction (whether positive or negative) for each supply chain agent depending on the ordering option of choice. Many studies have reported that information sharing does not provide benefit to some agents and others in the same supply chain are benefited (Yao and Dresner, 2008, Lau et al., 2002, Yu et al., 2002) and the reason for this discrepancy is not fully understood or at the least has not been shown but is believed to be due to the operating conditions of the supply chain. This study also aims to provide an answer to this question by confirming that the condition of the supply chain (structure and ordering policy type) is a factor to consider in information sharing decisions. The main question here is how does information sharing; supply chain structure; and ordering policy interact and what influence do these interactions have on supply chain performance? However this question can be decomposed into the following questions to paint a fuller picture:

Question 1a: *Given the same supply chain conditions, how does a batch ordering policy perform against a parameter based ordering policy, and how does the combined policy fare against the individual ordering policy types?*

Question 1b: *How does supply chain structural reconfiguration alone affect the performance of the three ordering policies mentioned?*

Question 1c: *Considering the simplification strategy, where along the supply chain should simplification be carried out, at the wholesaler tier or at the manufacturer tier?*

Question 1d: *Which strategy offers more benefit, the simplification strategy or the networking strategy?*

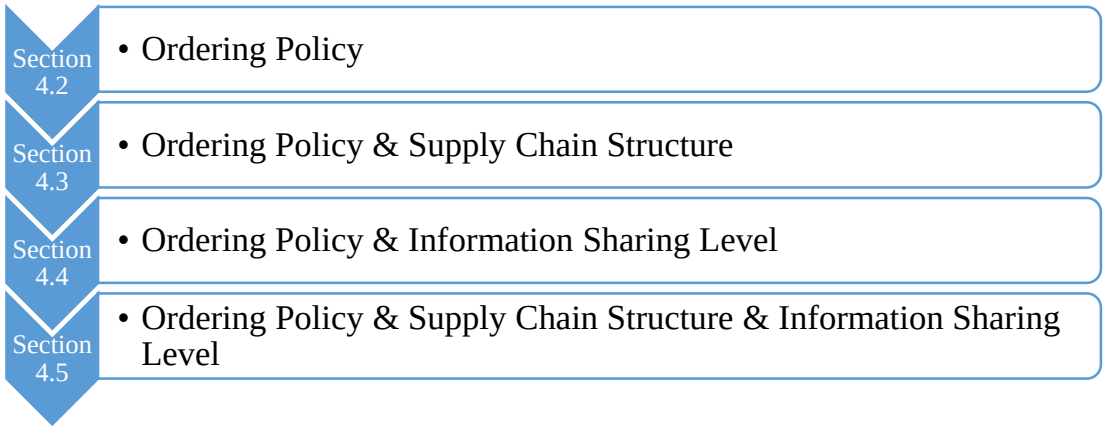
Question 1e: *How does varying the level of information alone affect the performance of the three ordering policies mentioned?*

Question 1f: *What is the interaction effect of supply chain structure and information sharing level on batch ordering, parameter based and the combined ordering policies?*

It should be noted that this study serves as a benchmark for evaluating the impact of information security breach on supply chain performance, which is one of the primary aims of this thesis. This is discussed in the next chapter. However the answer to the above questions has been elusive in previous studies and they can help inform supply chain managers on the counter-intuitiveness of certain combinations of strategic factors. This understanding will help businesses make better strategic decisions on supply chain configuration, ordering policy, and information sharing.

4.1.3 Structure of Chapter

This chapter examines the influence of information sharing under various supply chain conditions in a non-security breach scenario. The structure of this chapter is shown below.



Section 4.2 examines the behaviour and performance of all three ordering options in a serial supply chain without information sharing. This behaviour is examined according to the ordering pattern and the bullwhip effect inherent in each ordering policy and this serves as the base study. Section 4.3 then examines the effect of changing the structure of the supply chain from the serial type (base model) to the

other structure types, WH; MF and NT structures. Each structure is analysed to understand how the behaviour of each ordering policy is changed and the implication to supply chain performance and prioritisation. In section 4.4 the effect of engaging in varying levels of information sharing on the ordering pattern and bullwhip effect is examined. The implication to supply chain performance is then discussed. The subsequent section 4.5 begins to look at the influence of varying level of information sharing under different supply chain structures. In other words the interacting effect of information sharing and supply chain structure on the performance of each ordering policy is examined. This section examines the influence of RW, WM and RWM respectively on all supply chain structures under all three ordering policy scenarios and presents a summary of the result along with the implication to supply chain priorities.

The output of the simulation experiments is averaged over the 45 replications to give the average daily performance in terms of holding cost, backlog cost, and ordering cost under each information sharing scenario. The average fill rate is obtained by dividing the average order quantity sent to the downstream agent by the average order quantity placed by the same downstream agent. For each supply chain agent the daily average holding cost, backlog cost and ordering cost is added to give the daily operational cost and the operational cost of each agent is aggregated to give the supply chain total operational cost. This result can be found in Appendix 4.1. However for the purpose of discussion in this chapter the operational cost and the supply chain cost has been extracted from Appendix 4.1 and presented in Table 4.1.

		Daily Average Operating cost (£)											
		Option I				Option II				Option III			
		Retailer	Wholesaler	Manufacturer	SC Total	Retailer	Wholesaler	Manufacturer	SC Total	Retailer	Wholesaler	Manufacturer	SC Total
NI	BC	194.90	112.69	89.40	**396.99**	120.00	86.81	102.96	**309.77**	106.68	79.72	113.50	**299.90**
	WH	199.00	112.42	84.66	**396.08**	123.69	79.85	95.62	**299.16**	105.27	70.73	108.45	**284.45**
	MF	194.80	112.01	79.52	**386.34**	123.36	87.12	89.83	**300.30**	107.79	79.49	106.80	**294.08**
	NT	198.89	114.89	84.78	**398.56**	124.70	82.81	90.06	**297.56**	105.65	73.73	108.37	**287.74**
RW	BC	171.34	92.27	92.15	**355.76**	113.85	82.99	105.27	**302.12**	108.73	80.67	98.71	**288.11**
	WH	171.41	86.74	89.94	**348.09**	113.81	78.45	108.58	**300.84**	108.45	75.82	97.80	**282.07**
	MF	171.25	91.35	84.76	**347.35**	115.43	82.88	93.97	**292.28**	109.67	80.56	85.60	**275.82**
	NT	184.23	106.10	90.07	**380.39**	127.64	99.80	94.47	**321.91**	115.11	87.82	91.91	**294.83**
WM	BC	198.73	116.25	77.53	**392.51**	121.79	87.48	95.28	**304.55**	113.85	85.19	85.52	**284.57**
	WH	200.58	113.92	73.74	**388.24**	124.04	79.72	92.06	**295.83**	110.56	75.03	81.33	**266.92**
	MF	200.20	117.14	68.68	**386.03**	127.27	89.71	88.75	**305.72**	116.77	86.44	82.16	**285.37**
	NT	202.06	117.96	72.67	**392.70**	125.90	83.49	89.53	**298.91**	113.06	79.94	82.66	**275.67**
RWM	BC	155.57	78.77	79.65	**313.99**	114.22	81.81	91.26	**287.29**	109.92	81.31	86.46	**277.70**
	WH	153.23	70.35	80.00	**303.59**	113.93	76.16	91.83	**281.93**	109.18	75.64	86.04	**270.87**
	MF	155.91	78.51	69.60	**304.01**	116.32	81.98	82.63	**280.92**	110.33	80.98	77.74	**269.05**
	NT	169.34	94.12	76.33	**339.79**	129.81	101.17	84.81	**315.79**	116.09	88.48	83.36	**287.92**

Table 4.1 Supply chain performance under various supply chain scenarios

4.2 COMPARATIVE ANALYSIS OF THE PERFORMANCE OF THE THREE ORDERING POLICIES IN A SERIAL SUPPLY CHAIN SCENARIO

Under the non-integrated serial supply chain mode, the cost performance behaviour of each agent in the option I-supply chain is similar for all supply chain structures considered. The pattern is that the daily operating cost of the retailer is highest followed by that of the wholesaler and the manufacturer experienced the least cost. However, the pattern is different under options II and III. Here the daily operating cost is highest at the retailer but lowest at the wholesaler while the manufacturer has the median cost performance. Consequently option II and III have a similar trend for all examined supply chain structures while option I has a different one. This trend according to Table 4.1 appear to differ for each ordering policy based on the level of information sharing within the supply chain and the structure of the chain. To understand the anatomy of the difference in behaviour, each ordering policy is looked at more closely. To do this, an analysis of the ordering pattern is done coupled with a bullwhip effect analysis.

4.2.1 Ordering Pattern Anatomy of the Three Ordering Policies in a Serial Chain Structure (Base Model)

The ordering pattern has been defined in this study as a combination of the ordering rate (OR) and effective average order quantity (EAOQ) of each ordering policy. The ordering rate is expressed as a percentage and represents the portion of the number of days an order is placed against the total number of simulation days. For instance, a value of 100 shows that an order is placed 100% of the time, which means that an order is placed to the upstream member every day. A value of 50 means that an order is placed on the number of days that is equivalent to half the total simulation time of 701 days. The EAOQ on the other hand is the total order quantity divided by the actual ordering days. As a simple illustration, say 1000 units were made in total and the number of ordering days were 500 out of 701 total simulation days, then the average order quantity would be 1000/701. However the EAOQ would be 1000/500. Appendix 4.2 presents the percentage of time an order is placed (ordering rate) and the effective average order quantity for each supply chain agent under all examined supply chain scenarios.

In the methodology chapter it has been established that option I places an order whenever the inventory position falls below the re-order point, the quantity of which is equivalent to the difference between the order-up-to level (also re-order level) and the inventory position. From the ordering pattern result in Appendix 4.2 under the non-information sharing serial supply chain scenario (i.e. the base model) the order quantity for the retailer averages 9.98 which is less than the average demand quantity of 10. This means that the inventory position more often than not would be less than the re-order point prompting a daily order placement. The results suggest a 100% ordering rate which confirms that the retailer places an order every day. This of course would mean that the fill rate of the retailer would be low and consequently the backlog cost would be high. Since order quantity is not able to sufficiently satisfy demand, the expectation is that the holding inventory will be very low or near zero as there is constantly a demand that needs to be fulfilled. The result in Appendix 4.1 confirms this with the retailer fill rate very low (at 45%) and the backlog cost high (at £140). The holding cost for the retailer is near zero at £0.02. A similar observation is seen at the wholesaler and the manufacturer where the respective effective average order quantity is lower than the order from the downstream agent. Therefore the ordering rate is the same for all supply chain agents at 100% but the average effective order quantity decreases slightly as one goes upstream the supply chain.

For option II however, the order quantity is equivalent to the amount determined by a dynamic optimal EOQ model which is larger than that determined in the option I scenario. This quantity is large enough to better satisfy initial demand and raise the inventory position. Raising the inventory position implies that there would be less number of times the inventory position is lower than the re-order point. Therefore, orders would be placed less frequently and the inventory holding cost would be higher than in the option I scenario but the cumulative fixed ordering cost would be much lower. In addition the fill rate performance is expected to be higher under option II than in option I and consequently the backlog cost should be lower. From the result in Appendix 4.1, this expectation is confirmed to be true. Interestingly, the ordering rate decreases as one goes up the chain and the average effective order quantity significantly increases. This scale of increase in effective order quantity as one goes up the chain is high enough to create external economies of scale which

translates into an improvement in operational efficiency at the manufacturer. Therefore the manufacturer is able to enjoy a reduction in daily average inventory holding cost that would have otherwise been high considering the size of the wholesaler orders to it. The consequence of this again is that the backlog cost would then be higher than anticipated. Hence the fill rate performance of the manufacturer in option II (92%) is less than that in option I (95%) meaning the daily average backlog cost in Option II (£9) is higher than that in option I (£5). This would have been the other way round if not for the scale increase effect.

Option III is an extension of option I (the base stock policy) with the addition of the simple EOQ component to its order quantity determination. This quantity is larger than the quantity in option I but less than that in option II. Therefore, orders would be placed less frequently in option III than in option I but more frequently than in option II. Consequently inventory holding cost would be higher under option III than in the option I scenario, but less than the option II scenario and the cumulative fixed ordering cost would be lower in option III than in option I but higher than the option II scenario. However the holding inventory for the manufacturer in option III is higher than in option II. This has been explained in the previous paragraph. The reason is because the scale increase effect was observed at the manufacturer under option II but not under option III as the order size is not large enough to create this effect in option III. This effect in option II is however large enough to ensure better daily average inventory holding cost performance in option II than in option III. Option III appears to be in between option I and option II in terms of the ordering pattern performance and the fill rate performance under this option is better than the other two ordering options. This suggests that the balance between the ordering rate and the EAOQ in option III creates a better balance between how much is ordered against how much is being demanded making it the best cost performer of the three ordering options.

In summary, option I is such that the ordering rate is high and the EAOQ is low and this is classed as a Case-1 ordering state. Option II is such that the ordering rate is low and the EAOQ is high and this is classed as a Case-2 ordering state. Comparatively, option II (£310) performed better than option I (£397) which means Case-2 scenario is more desirable than Case-1 scenario under normal circumstances. Option III, however, has median ordering rate and median average effective order

quantity existing between the Case-1 and Case-2 ordering states. This state appear to be the nearer-optimal state making it the best overall cost performer (£300) of the three ordering policy.

4.2.2 Anatomy of the Bullwhip Effect in a Non-Integrated Serial Chain Structure (Base model)

The bullwhip effect has been described in literature as an amplification of order variance which increases as one goes from the demand side to the supply side (Sterman, 1989, Lee et al., 1997, Lee et al., 2004). The order quantity variance of each supply agent for all the examined supply chain scenarios is computed in MS Excel and shown in Appendix 4.3. The result in Appendix 4.3 reveals that under the non-information sharing scenario, the order variance increases as one goes from the downstream demand side to the upstream supply side and this was found for all three ordering policies. The implication of the bullwhip effect from past literature is that upstream agents tend to carry excess inventory and therefore incur higher inventory holding cost (Lee et al., 1997). This is confirmed for each ordering policy. The holding inventory cost of the retailer is lowest and that of the manufacturer is the highest with the wholesaler experiencing the median holding inventory cost as seen in Appendix 4.1. This trend is observed in all three ordering policies for all the supply chain structures considered, which in a way validates the simulation models used in this study.

The above analysis is an intra-supply chain ordering policy bullwhip assessment meaning the trend was observed separately under each ordering option in each supply chain scenario. The next phase of analysis is an inter-supply chain ordering policy bullwhip assessment meaning each ordering policy is compared to one another based on the magnitude of the bullwhip effect observed. However, to compare the three ordering policies in terms of their respective bullwhip quantification and the implication to inventory holding cost, two methods of order amplification ratio have been suggested in the literature. The first method captures the order amplification as the ratio of the order variance of each supply member to that of the consumer demand as described in Chen et al. (2000) and Hosoda and Disney (2006). In other words, the order variance at the retailer is divided by the variance of the consumer demand and the wholesaler order variance is divided by the variance of the consumer demand as well and this also applies to the manufacturer.

The second method applies the concept of control theory defined in Hosoda and Disney (2006) (citing Jury, 1974). According to this control theory, the order amplification is calculated as a ratio of output to input which means the variance of retailer's order quantity is divided by the variance of the consumer demand, while that of the wholesaler is divided by that of the retailer; and that of the manufacturer is divided by that of the wholesaler. The result of both calculations for all supply chain scenarios can also be found in Appendix 4.3. By comparing the result of both methods of order amplification calculation to the inventory holding cost performance of each supply chain agent across the each ordering policy in Appendix 4.1, it was found that the second method (the control theoretic perspective) was more consistent in confirming the relationship of the bullwhip effect to inventory performance of the supply chain. The amplification ratio of the retailer was highest under option II then followed by option III and option I had the least ratio in the serial supply chain scenario. In the same way, similar trend is observed in Appendix 4.1 for the inventory holding cost performance of the retailer under the three ordering policies. This sort of direct comparison between the three ordering options is applicable because they were all subjected to the same supply chain condition/variables. The inventory holding cost of the retailer is highest under option II, then option III and least under option I. Comparing the performance of the wholesaler and the manufacturer in the same way yields the same observation and this trend is consistent for all observed supply chain structures.

Doing the comparison at the supply chain level, Option I exhibits stability in the bullwhip effect (that is no apparent bullwhip effect as the order amplification is unitary) where the order amplification ratio is more or less the same as you move up the supply chain. This is because the average order quantity in this ordering policy for each supply chain agent is slightly lower than the average market demand. Consequently the bullwhip effect is not very apparent, although there is slight increase in order variance as one goes upstream as the result in Appendix 4.3 reveals. This is perhaps part of the reason why the backlog cost in this policy rule is very high since, according to Disney and Lambrecht (2007), lower bullwhip effect has negative consequence to customer service level.

Option II on the other hand exhibits partial bullwhip effect at the interface between the wholesaler and the manufacturer. The control theory order amplification ratio of

the manufacturer (1.73) is much less than that of the wholesaler (4.66). This observation is consistent with the findings of Baganha and Cohen (1998) where a fixed order quantity is used and their study suggest that the wholesaler has a stabilizing effect on variance amplification in such an ordering policy. One would have anticipated that the manufacturer will incur the highest holding cost under option II (much greater than the £39.2 in the serial scenario and even greater than £56.6 under option III serial scenario) but the reduction in amplification ratio between the wholesaler and the manufacturer reveals why this is not so. This also corroborates the explanation offered in section 4.1.1 that the manufacturer enjoyed increased operational efficiency under option II due to the scale of increase in effective order quantity as one goes up the supply chain. The partial bullwhip effect at the wholesaler/manufacturer interface suggest that the variance of the orders placed by the wholesaler to the manufacturer is not as large as it should have been because of the stabilising effect of the wholesaler resulting in the reduction of safety stock estimation at the manufacturer. This therefore allows the manufacturer to enjoy reduced inventory holding cost under option II. Therefore option II inherently offers bullwhip protection especially to the manufacturer.

Option III on the other hand showed bullwhip effect consistency as the order amplification increased as one goes upstream the supply chain and there is no apparent stabilising effect of the wholesaler. Consequently the supply chain total holding inventory cost for option III was greater than for option II with partial bullwhip effect and that of option I was least due to having minimal bullwhip effect.

4.2.3 Summary of Findings and Discussion

This section deals with Question 1a set at the start of the chapter.

Question 1a: *Given the same supply chain conditions, how does a batch ordering policy perform against a parameter based ordering policy, and how does the combined policy fare against the individual ordering policy types?*

All the observations under the serial structure were consistent for all other structures considered which validates the findings of this study. The finding of this aspect of the study is summarised below:

- Each of the three ordering policies excelled in different aspects. The base stock policy (option I) fared much better than the other two in terms of the bullwhip effect; the optimal EOQ model (option II) enjoyed the least ordering frequency because of the size of each order quantity which could be an advantage depending on how big the fixed ordering cost is; while the combined policy (option III) enjoyed the least operating cost of the three.
- A direct comparison between the optimal EOQ model (batch ordering policy) and the base stock model (parameter based policy) revealed that the optimal EOQ ordering type would require a shipping strategy that favours higher order quantity with less ordering frequency while a base stock policy under the same supply chain condition would require a shipping strategy that favours lower order quantities ordered more frequently.
- Overall, under normal circumstances, the base stock policy is a worse cost performer than the optimal EOQ model and the combined batch-and-parameter based model is the best cost performer of the three.

As the result in Appendix 4.1 suggests, bullwhip effect does cause an increase in the inventory holding cost performance of the supply chain providing further evidence to back up what has been established in past literature. However, this study provides further evidence which has not been fully established in past literature in establishing a bullwhip comparison of different supply chain ordering policies under similar supply chain conditions and how this links to inventory holding cost performance of the supply chain.

The performance trend of all three ordering policies in the serial structure was similar in the wholesaler, manufacturer and network structures but only differ in magnitude. The magnitude of the difference in performance level is the basis of this study's structural comparison. This is discussed in the next section.

4.3 THE INFLUENCE OF RE-STRUCTURING ALONE ON ORDERING POLICY PERFORMANCE IN A NON-INTEGRATED SUPPLY CHAIN SCENARIO

To understand how structure affects supply chain performance, the performance under the three supply structures (WH, MF and NT) are compared to the serial structure (which is also termed the 'base model') performance. The first step of

examination is to see how the ordering pattern and the bullwhip effect changes when you move from the serial structure to the other three structure types. The second step of examination is to assess the implication of this change to supply chain cost performance.

4.3.1 Effect of Structural Change on the Ordering Pattern of Options I, II and III

The change in ordering pattern is conceptualised as the change in ordering frequency and effective daily average order quantity. The change brought about by restructuring in ordering frequency/rate is calculated by taking the difference between the ordering rate (expressed in %) in the base model and the corresponding ordering rate in the WH, MF and NT structures. On the other hand, the change in average effective order quantity is calculated as the difference between the values in the base model and the corresponding structure but is expressed as a percentage of the base model. The result for this computation for each ordering policy under each structure type is shown in Table 4.2. For each ordering option, the original or initial values in the base model is included in the first three rows of the table and the respective changes in ordering rate and effective average order quantity (EAOQ) due to all three structures is included under the corresponding label. A negative value indicates that the value in base model is lesser than that in corresponding WH, MF and NT structures, while a positive value indicates otherwise.

The general observation from this table is that restructuring the supply chain from the serial structure to any of the WH, MF and NT structures has no impact on the ordering pattern of option I. However this has an effect on option II and option III with the magnitude of change generally higher in option II than in option III. The direction of the change is that the ordering frequency is higher while the effective average order quantity is lower than in the serial structure.

Therefore, understanding how the ordering pattern changes when restructuring is being considered in the supply chain is crucial for many organisations and supply chains to understand if there is need to change the shipping strategy. For example, the best shipping option may be selected based on the frequency of delivery and the capacity of the shipping mode. If the frequency of ordering then reduces and the quantity is increased, then the initial shipping strategy may no longer be the optimal

option. It may then be worthwhile to change the shipping strategy to best suit the current ordering pattern.

Ordering Pattern in the Base model						
	Retailer		Wholesaler		Manufacturer	
	O R (%)	EAOQ	OR (%)	EAOQ	OR (%)	EAOQ
Option I	100	9.98	100	9.97	100	9.94
Option II	89	11.28	62	16.00	49	20.36
Option III	98	10.18	89	11.16	67	14.81
Effect of WH on a serial Supply Chain						
Option I	0.00	0.00%	0.00	0.00%	0.00	0.00%
Option II	-0.10	0.11%	-0.07	0.09%	-0.13	0.21%
Option III	-0.02	0.02%	-0.07	0.07%	-0.08	0.10%
Effect of MF on a serial Supply Chain						
Option I	0.00	0.00%	0.00	0.00%	0.00	0.00%
Option II	-0.10	0.11%	-0.24	0.27%	0.01	-0.03%
Option III	-0.02	0.02%	-0.09	0.09%	-0.02	0.03%
Effect of NT on a serial Supply Chain						
Option I	0.00	0.00%	0.00	0.00%	0.00	0.00%
Option II	-0.10	0.11%	-0.25	0.29%	-0.18	0.26%
Option III	-0.02	0.02%	-0.07	0.07%	-0.06	0.08%

Table 4.2 Effect of supply chain structure on ordering pattern

4.3.2 Effect of Structural Change on the Bullwhip Effect Inherent in Options I, II and III

In terms of the change to bullwhip effect, the general observation from Appendix 4.3 is that restructuring does not bring about any significant changes to the magnitude of order variance of each supply chain agent in option I but significant changes are seen in the order variances in option II and option III. The order variance of the retailer is slightly reduced under option II but increased slightly under option III for all WH, MF and NT supply chain structures. The WH structure significantly increases the order variance of the wholesaler and the manufacture under option II but it reduces the order variance of the wholesaler and increases that of the manufacturer in option III. The MF structure keeps the order variance of the wholesaler the same but

increases that of the manufacturer under both under option II and option III scenarios. The NT structure reduces the order variance of the wholesaler and increases that of the manufacturer under options II and III. For all supply chain structures considered, the highest percentage reduction in supply chain daily average inventory holding cost occurred under option II because of its inherent partial immunity to the bullwhip effect.

Managerial Insight: Restructuring the supply chain to the WH, MF and NT type structures alters the bullwhip dynamics of the supply chain by reducing the order variance at one tier and increasing it at another. The effect of this is a reduction of the total supply chain daily average inventory holding cost. This means that efforts to simplify the supply chain using WH, MF and NT strategies would reduce the total supply chain daily average inventory.

4.3.3 Implication of Structural Change to the Supply Chain Performance under Options I, II and III scenario

Having examined the changes to ordering pattern and bullwhip effect, the implication of these changes to supply chain cost performance is now examined. The magnitude of the difference between the cost performances of each structure to that of the base model is expressed as a fraction of the base model performance. In other words the difference between the performance of the other structures and the base model is divided by the performance of the base model. This relative comparison to that of the serial structure is termed 'structure effect'. For example the WH-effect would be the difference between the performance of the Wholesaler supply chain structure and the base model expressed as a fraction of the base model performance. In the same light the MF-effect and the NT-effect are measured against the base model. This fractional difference (or percentage difference if multiplied by 100) is tested for significance at $p<0.05$. The idea for this comparison is to show, with confidence, whether supply chain reconfiguration from the base model to any of the other structure type is beneficial or detrimental to the performance of the supply chain as measured by the magnitude and the statistical significance of the percentage difference. For example if there is an obvious percentage change (be it positive or negative) but this change is not statistically significant at $p<0.05$, then the structure effect is said to be non-existent (no effect). The structure effect on each supply agent

for each of its performance measures (daily average holding, backlog and ordering costs) is computed as described above and shown in Table 4.3.

Base Model Performance								MF Effect (%)				
		Holding (£)	Backlog (£)	Ordering (£)	Total (£)	Fill Rate (%)		Holding	Backlog	Ordering	Total	Fill Rate
Option I	Retailer	0.04	140.04	54.83	**194.90**	0.42		-1nd	0	0nd	**0**nd	0
	Wholesaler	1.93	55.97	54.80	**112.69**	0.64		5nd	1nd	0nd	**1**nd	0
	Manufacturer	24.69	5.09	59.62	**89.40**	0.95		12nd	42nd	8	**11**	2
	Total	**26.66**	**201.10**	**169.24**	**396.99**			**11**	**1**	**3**	**3**nd	
Option II	Retailer	2.41	63.35	54.25	**120.00**	0.61		12nd	-6	0nd	**-3**nd	-1
	Wholesaler	16.98	16.90	52.93	**86.81**	0.86		7	-9nd	0nd	**0**nd	-1
	Manufacturer	39.21	9.07	54.68	**102.96**	0.92		22	22	4	**13**	2
	Total	**58.60**	**89.32**	**161.85**	**309.77**			**17**	**-3**	**1**	**3**	
Option III	Retailer	1.94	50.01	54.73	**106.68**	0.67		8	-2	0	**-1**	0
	Wholesaler	12.90	12.56	54.26	**79.72**	0.89		5	-3	0	**0**	0
	Manufacturer	56.60	0.60	56.30	**113.50**	0.99		6	68	6	**6**	0
	Total	**71.44**	**63.17**	**165.28**	**299.90**			**6**	**-2**	**2**	**2**	

nd- not statistically significant at $p<0.05$.

Table 4.3 Structure effect in a no-breach-scenario

		WH Effect (%)						Network Effect (%)				
		Holding	Backlog	Ordering	Total	Fill Rate		Holding	Backlog	Ordering	Total	Fill Rate
Option I	Retailer	40nd	-3nd	0nd	**-2**nd	-1		42nd	-3	0nd	**-2**nd	-1
	Wholesaler	76	-6nd	4	**0**nd	-1		72	-6nd	0nd	**-2**nd	-1
	Manufacturer	11nd	40nd	0nd	**5**	2		11nd	38nd	0nd	**5**	2
	Total	**16**	**-3**	**1**	**0**nd			**16**	**-3**	**0**	**0**nd	
Option II	Retailer	13	-6	0nd	**-3**	-1		24	-8	0nd	**-4**	-2
	Wholesaler	45	-11	2	**8**	-1		48	-22	-1	**5**	-3
	Manufacturer	12	30	0nd	**7**	2		28	20	0nd	**13**	2
	Total	**21**	**-3**	**1**	**3**			**34**	**-8**	**0**	**4**	
Option III	Retailer	7nd	3nd	0nd	**1**nd	1		9nd	2	0nd	**1**nd	0
	Wholesaler	38	17	4	**11**	2		36	14nd	-1	**8**	1
	Manufacturer	9	49nd	0nd	**4**	0		9nd	43nd	0nd	**5**	0
	Total	**14**	**6**	**1**	**5**			**14**	**5**	**0**	**4**	

nd- not statistically significant at $p<0.05$.

Table 4.3 Continued

However for the fill rate performance, the difference is taken directly as is and not expressed as a fraction of the base model.

The direction of the structure effect can be of a positive type or a negative one. A positive value reveals that the cost in the base model is higher than that of the corresponding structure indicating a beneficial structure effect while a negative value indicates a detrimental structure effect. Values with superscript 'nd' indicate that the fractional difference is not statistically significant at $p<0.05$ and therefore no effect is said to occur regardless of the magnitude of the fractional difference. Also, for the fill rate performance a positive value shows that the fill rate performance of the base model is lower than that of the other structures revealing a beneficial structure effect while a negative value is indicative of a detrimental effect. It is also important for each supply agent to understand which structure is most beneficial to their operational cost performance and where incentives may lie. If adopting any of the three proposed structures yields benefit to the supply chain, then that structure could be seen as a beneficial strategy which should only be adopted when all supply members are benefiting. However if some are not benefited the decision framework shown in Figure 4.1 can be followed to arrive at an 'acceptance', 'rejection' or 'acceptance after incentivisation' decision. Therefore using Table 4.3, the structure effect on individual performance is discussed in the following subsections.

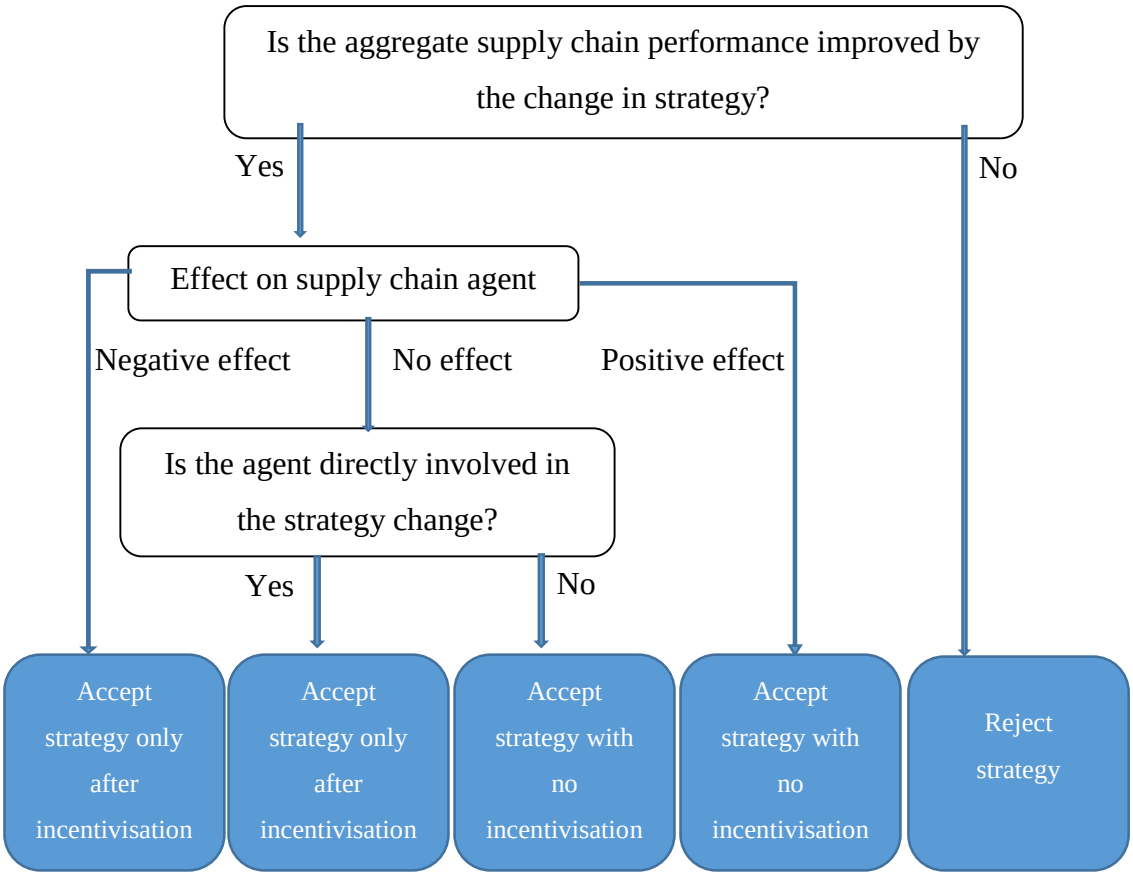


Figure 4.1 Single strategy acceptance decision framework in a non-breach scenario

4.3.3.1 WH-Effect on supply agent individual performance

From Table 4.3, it is shown that for ordering option I the WH structure has no effect on the total operating cost of the retailer and the wholesaler but significantly affects that of the manufacturer. However the positive effect on the manufacturer's daily operating cost is not big enough to cause an overall supply chain performance improvement.

Under option II, the WH structure had a significant effect on all supply agents daily cost performance although the retailer experienced an increase in cost performance while the wholesaler and the manufacturer experienced an improvement in cost performance. The aggregate of the improvement at the wholesaler and the manufacturer causes an overall positive effect on supply chain performance despite the negative impact on the retailer. Therefore incentive can be provided to the retailer by the wholesaler and the manufacturer if the retailer is to be persuaded to accept this type of structure. It is to be noted however that the wholesaler

experiences the greatest benefit from this structure type which appear plausible as the structure, in theory, should favour the wholesaler more.

With option III, WH effect is not significant for the retailer but significant for the wholesaler and the manufacturer. Therefore the retailer can be further incentivised to encourage participation in this type of structure. Again, like under option II, the wholesaler is the highest cost improvement beneficiary of this type of structure.

Comparing the effect of WH on the three ordering options, the general observation is that option III seems to benefit the most.

4.3.3.2 MF-effect on supply agent individual performance

The MF structure has no significant effect on the daily operating cost performance of the retailer and wholesaler under option I as shown in Table 4.3. The effect is however significant on the performance of the manufacturer but the improvement seen at the manufacturer is not large enough to cause a significant effect on supply chain cost performance although the supply chain cost improvement is noticeable at 3% but not significant at $p<0.05$. The implication of this is that the retailer and the wholesaler would not be inclined to be associated with this structure type if the ordering policy is the base stock policy type.

The effect under option II is similar to that under option I. The daily total operating cost of the retailer and the wholesaler are not significantly affected by a transformation from a serial structure to a MF structure type but that of the manufacturer is. Unlike the observation under option I, the improvement at the manufacturer is large enough to cause a significant improvement on the supply chain daily operating cost.

Examining the effect under option III, the MF structure does not significantly affect the daily operating cost performance of the retailer and the wholesaler but significantly improves the performance of the manufacturer by 6%. The effect is however significant on the aggregate supply chain performance.

Again the manufacturer benefits the most under this structure as expected, while the effect is not significant on the retailer and the wholesaler's cost performance. The benefit to the manufacturer is however large enough to provide added cost incentive

to the retailer and the wholesaler. Comparatively, option III experiences the best cost performance under the MF structure of the three ordering policies.

4.3.3.3 NT-effect on supply agent individual performance

The daily operational cost performance of Option I is not significantly affected by structural change from serial to network type structure. It appears that although the network effect improves the manufacturer's daily operational cost performance significantly by 5%, the retailer and the wholesaler on the other hand are not benefiting at $p<0.05$. The benefit to the manufacturer however appears to be inconsequential to the overall supply chain performance, therefore the retailer and the wholesaler would not be inclined to operate in such a structure.

Clearly the network effect is quite beneficial under an option II scenario especially to the wholesaler and the manufacturer, with the most favoured agent being the manufacturer. It is however not favourable towards the retailer as there is a 4% increase in daily operating cost which is significant at $p<0.05$. Despite this negative effect on the retailer, the benefit generated towards the wholesaler and the manufacturer can still provide good incentives to cover the retailer's increased cost, at the least.

Of the three ordering policies, option III seems to be the best option for the network type structure when all supply chain agents are considered. The NT-effect produced a significant improvement in the daily operational cost performance of all supply agents under this ordering policy with the wholesaler receiving the most benefit.

In general, the network structure is more favourable towards option III and II, with the wholesaler benefiting the most under option III and the manufacturer under option II. Option I however does not benefit from a transmogrification into a network structure as the effect experienced is not significant at $p<0.05$.

4.3.3.4 General effect of structural change to the performance measures

The holding cost, backlog cost and the ordering cost performances are affected in different ways depending on the structure and ordering policy of choice. The WH effect to options I, II and III is a reduction in holding inventory resulting in a reduced inventory holding cost performance of all supply chain agents. This reduction in holding inventory was significant enough to cause a reduction in fill rate performance especially for the retailer and the wholesaler. The reduction for the

manufacturer was not significant enough to cause a drop in fill rate performance; rather it was just enough to raise the fill rate performance of the manufacturer. This effect on fill rate performance means the backlog cost performance would be affected in a similar fashion as the better the fill rate the better the backlog performance and vice versa. The backlog cost for the retailer and the wholesaler was negatively affected by the WH structure under option I and II while that of the manufacturer was positively affected as suggested by the improvement in manufacturer's fill rate performance. The effect on the overall cost performance for both retailer and wholesaler was insignificant because the rise in backlog cost was evened out by the reduction in holding cost. The effect of WH on option III was a reduction in holding cost and also backlog cost. The reason for this behaviour, contrary to that of options I and II, is that option III is a rather near-optimal policy where the ordering pattern is enough to ensure a good balance between holding cost and backlog cost performance as revealed in section 4.2.

4.3.4 Summary of Findings and Discussion

This section provides an answer to Question 1b.

Question 1b: *How does supply chain structural reconfiguration alone affect the performance of the three ordering policies mentioned?*

From the study, one can infer that changing the structure can either provide benefit or not to supply chain cost performance depending on the existing ordering policy in the supply chain. The findings on the effect of structural reconfiguration on the bullwhip effect, ordering pattern and supply chain cost performance is summarised below:

- Reconfiguring from a serial structure to any of the other three structures does not change the nature of bullwhip effect for all the three ordering policies investigated. The bullwhip effect in any of the new structures (WH, MF and NT) is minimal under option I, partial under option II and consistent under option III which is consistent with the findings in section 4.2, although the magnitude of order variance varies under each ordering policy depending on the type of supply chain structure. This consistency in result also validates the simulation model.

- The general effect of structural reconfiguration on the ordering pattern of the supply chain agents in options II and III scenarios is a reduction in the effective average order quantity (EAOQ) and a commensurate increase in ordering rate (OR). There is no apparent effect on the ordering pattern when the ordering policy is the parameter based policy (Base stock policy-option I). Therefore, from the result, one can infer that supply chains using the parameter based policy (base stock policy) need not change their shipping strategy when considering structural reconfiguration, but those using batch or combined batch-and-parameter based models should revisit their shipping strategy to adopt one that favours lesser order quantity placed more frequently.
- At the supply chain level, a supply chain with the base stock policy (option I) does not enjoy any cost improvement benefit when considering supply reconfiguration from a serial type structure to WH, MF or NT structure types. Although under the MF structure, the supply chain operating cost is seen to reduce by 3%, this increase is not statistically significant at $p< 0.05$ according to the t-test assessment. Options II and III on the other hand enjoy significant cost improvement benefit from supply reconfiguration into WH, MF and NT structure types. Interestingly, the WH structure favours option III more than option II while MF favours option II above option III. The NT structure favours option II and option III equally.
- Changing the structure of a supply chain can be difficult especially for those organisations in existing serial structures. For a supply chain using batch ordering policy (e.g. optimal EOQ model) who wants to derive the benefit of structural change but does not want to go through the hassle of restructuring should consider only modifying its policy to the combined batch-and-parameter based policy to reap similar benefits.

A summary of the effect of structural reconfiguration on individual cost performance of supply agents and the supply chain as a whole is shown in Table 4.4. The symbol '>' indicates that the supply chain agent or the aggregate supply chain experience a beneficial effect when reconfiguration takes place, while the '<' indicate a detrimental effect and as such there is no inclination to adopt that specific structure. The '-'symbol indicates that the effect is not significant and hence the respective

supply agent would be indifferent to adopting such structure. Going by the decision framework in Figure 4.1, the result in Table 4.4 also indicate whether incentives can be provided for the non-benefiting supply chain agents as long as the overall effect of restructuring is positive. A beneficial effect or one where incentives can be provided is a good motivator for structural reconfiguration. To whom incentive is to be provided is also included in the last row of the table. The letters R refers to the retailer, W refers to the wholesaler and M refers to the manufacturer.

	Option I			Option II			Option III		
	WH	MF	NT	WH	MF	NT	WH	MF	NT
Retailer	-	-	-	<	-	<	-	<	-
Wholesaler	-	-	-	>	-	>	>	-	>
Manufacturer	>	>	>	>	>	>	>	>	>
Supply Chain	-	-	-	>	>	>	>	>	>
Acceptable?	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Incentivisation?	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Incentive to?	None	None	None	R	W	R	R	R,W	R

Beneficial effect (>), no significant effect (-), detrimental effect (<)

Table 4.4 Effect and motivation for structural reconfiguration

From the table it can be seen that only the manufacturer benefits from all types of structural reconfiguration under option I and no incentive can be provided to non-benefiting members since the overall effect is nil. Therefore there is no motivation for reconfiguration under option I, at least for the retailer and wholesaler. There is overall benefit to the supply chain under options II and III for all types of structural reconfiguration. However incentives need to be provided to the retailer/wholesaler/both depending on which structure strategy is adopted.

A summary of the answer to Question 1c is provided below:

Question 1c: *Considering the simplification strategy, where along the supply chain should simplification be carried out, at the wholesaler tier or at the manufacturer tier?*

- From the result, the simplification strategy where the number of manufacturers are reduced is best suited for the base stock policy, although the benefit of this strategy is not statistically significant under the base stock policy.
- For the batch ordering type e.g. optimal EOQ model, there is no preference as simplification at the wholesaler tier or the manufacturer tier yields the same benefit, however incentive has to be given to the retailer if the simplification is at the wholesaler tier, or to the wholesaler if the simplification is at the manufacturer tier.
- The ordering policy that combines the batch order quantity and parameter determined e.g. modified base stock policy (option III), would benefit more from simplifying the wholesaler tier than simplifying the manufacturer tier and incentive has to be given to the retailer only in this strategy.

A summary of the answer to question 1d is as follows:

Question 1d: *Which strategy offers more benefit, the simplification strategy or the networking strategy?*

- For the parameter based policies such as the base stock policy, again neither simplification nor networking strategies offer any significant benefit to the supply chain, hence adopting either of these strategies is basically futile.
- For batch ordering policies such as the optimal EOQ model, the better strategy would be to share the orders between agents of the same tier rather than simplify the supply chain at either the wholesaler or the manufacture tiers, although the latter strategy still holds benefit.
- For the combined policy type such as the modified base stock policy with EOQ component, the preferred strategy is the simplification strategy at the wholesaler tier rather than networking strategy.

However it is not yet understood how the performance under the discussed structures would be changed if and when the supply chain engages in information sharing. To understand this, the information sharing level (ISL) effect on the base model is first discussed followed by an examination of how the structure effect under the ISL influence affects the performance of the supply chain as a whole and the performance of each individual agent.

4.4 EFFECT OF ISL ALONE ON A NON-INTEGRATED (NI) SERIAL SUPPLY CHAIN

To understand how ISL affects supply chain performance, the performance of the serial supply chain under the three Integration levels RW, WM and RWM are compared to that of the non-integrated (NI) serial mode (which is also termed the 'base model'). The first step of examination again is to see how the ordering pattern and the bullwhip effect changes when you move from the NI mode to the other three integration modes. The second step of examination is to assess the implication of this change to supply chain cost performance at the operational level and at the supply chain level.

4.4.1 Effect of ISL on Ordering Pattern

The effect of information sharing on the ordering pattern of a serial supply chain is calculated in a similar way to Table 4.2 and presented in Table 4.5. The layout of the table has been described in section 4.3.1. Again, a negative value indicates that the value in non-integrated (NI) base model sharing is lesser than that in corresponding RW, WM and RWM information sharing modes, while a positive value indicates otherwise.

It is clear from the result that regardless of the information sharing level, no change to ordering pattern occurs in the base stock policy (option I). However, there are noticeable changes in option II and option III for certain supply chain agents depending on the level of information sharing and the direction of change is in contrast to the direction of change caused by restructuring. Engaging in information sharing reduces the ordering rate of a serial supply chain with commensurate increase in effective average order quantity (EAOQ) while structural reconfiguration alone causes an increase in the ordering rate with a commensurate decrease in EAOQ. Again, under options II and III, the ordering pattern of the retailer is not perturbed by any level of information sharing.

	NI-Serial Supply Chain					
	Retailer		Wholesaler		Manufacturer	
	OR (%)	EAOQ	OR (%)	EAOQ	OR (%)	EAOQ
Option I	100	9.98	100	9.97	100	9.94
Option II	89	11.28	62	16.00	49	20.36
Option III	98	10.18	89	11.16	67	14.81
Effect of RW on Serial Supply Chain						
Option I	0.00	0%	0.00	0%	0.00	0%
Option II	0.00	0%	0.12	-25%	0.00	0%
Option III	0.00	0%	0.18	-26%	-0.02	2%
Effect of WM on Serial Supply Chain						
Option I	0.00	0%	0.00	0%	0.00	0%
Option II	0.00	0%	0.00	0%	0.10	-24%
Option III	0.00	0%	0.00	0%	0.12	-22%
Effect of RWM on Serial Supply Chain						
Option I	0.00	0%	0.00	0%	0.00	0.00
Option II	0.00	0%	0.12	-25%	-0.06	12%
Option III	0.00	0%	0.18	-26%	-0.14	17%

Table 4.5 Effect of ISL on ordering pattern in a serial supply chain

Integration between the retailer and the wholesaler only (RW) significantly affect the ordering pattern of the wholesaler alone under option II but affects both the wholesaler and manufacturer under option III with the manufacturer only slightly perturbed. The integration between the wholesaler and the manufacturer (WM) only affects the ordering pattern of the manufacturer in the supply chain while the wholesaler and retailer are unperturbed. Under option II and option III, RWM being the integration between the retailer, wholesaler and manufacturer decreases the ordering rate of the wholesaler and manufacturer while increasing their respective EAOQ.

Managerial Insight: Again understanding the direction of change due to information sharing is important in determining if the current shipping strategy needs to be changed based on the magnitude of change created by such information sharing initiatives. Hence a shipping option that favours more delivery quantities with less delivery frequency is ideal under information sharing modes for the affected parties.

4.4.2 Effect of ISL on Bullwhip Effect

Regarding the bullwhip effect, Appendix 4.3 reveals that the order variance of the retailer in a non-integrated supply chain is unaffected when the supply chain engages in information sharing at any level. This is expected because the model assumption is that the retailer is always privy to market demand for all information and non-information sharing scenarios. However the order variance of the wholesaler and the manufacturer is affected depending on the information sharing mode. Engaging in information sharing at the RW level reduces the order variance of the wholesaler and manufacturer under option I scenario. Under option II scenario, the order variance of the wholesaler is increased while that of the manufacturer remains approximately the same. This implies that the manufacturer's estimate of safety stock would be increased which may result in the manufacturer carrying more inventory than is actually needed. In option III, RW causes an increase in wholesaler's order variance while that of the manufacturer is slightly reduced. Examining the effect of RW on the bullwhip effect using the result from the control theory calculation, it is found that RW does not change the bullwhip effect status in options I and II but the status of the bullwhip effect in option III is changed from full to partial bullwhip at the interface between the wholesaler and the manufacturer.

Under the WM mode, the status quo is maintained with regards to the bullwhip effect, only the manufacturer's order variance is altered in all three ordering policy scenarios. There is a slight reduction in manufacturer's order variance in the option I scenario but in options II and III scenarios, there is a significant increase in manufacturer's order variance.

RWM being the full integration mode has the same effect as the RW mode on the retailer's and the wholesaler's order variances for all ordering policy scenarios. However, the manufacturer's order variance is further reduced in the RWM mode compared to the RW mode for all three policies. Again RWM changes the bullwhip effect status of option III from full to partial at the wholesaler/manufacturer interface.

Managerial Insight: engaging in information sharing also alter the bullwhip dynamics of the supply chain by increasing the order variance in certain tiers and reducing it or keeping it the same in others depending on the type/level of

integration. The WM only affects the order variance of the manufacturer while RW and RWM affect both wholesaler and manufacturer. Hence the manufacturer is the only one enjoying a consistent and significant reduction in holding inventory under all information sharing scenarios (except under option II in the RW mode) and this benefit is highest under the WM mode. However, due to the accessibility to market demand information in the RW and RWM modes a better balance between what needs to be ordered to satisfy what has been demanded is kept.

Having examined the changes to ordering pattern and bullwhip effect brought about by information sharing, the implication of these changes to supply chain cost performance is now examined. The magnitude of the difference between the cost performances of each ISL to that of the base model is expressed as a percentage of the base model performance

4.4.3 Implication of ISL to a NI Supply Chain Performance under Options I, II and III scenarios

In order to examine the influence of ISL on supply chain performance, the difference between the cost performance in the various information sharing mode and the NI mode, which can be found in Appendix 4.1, is expressed as a fraction of the NI mode performance while that of the fill rate performance is expressed as is and not as a fraction of NI mode. The result of this computation is shown in Table 4.6 which is similar to how Table 4.3 was generated. Looking at the Table 4.6, the section under NI represents the performance of the non-integrated supply chain expressed in pounds. However the sections labelled RW effect, WM effect and RWM effect represent the percentage change that has been computed as described above.

		NI (in £)						RW Effect (in %)				
		Holding (£)	Backlog (£)	Ordering (£)	Total (£)	Fill Rate (%)		Holding (%)	Backlog (%)	Ordering (%)	Total (%)	Fill Rate (%)
Option I	Retailer	0.04	140.04	54.83	**194.90**	0.42		-86	17	0nd	**12**	5
	Wholesaler	1.93	55.97	54.80	**112.69**	0.64		-170	42	0	**18**	12
	Manufacturer	24.69	5.09	59.62	**89.40**	0.95		77	-424	0	**-3nd**	-16
	Total	**26.66**	**201.10**	**169.24**	**396.99**			**59**	**13**	**0**	**10**	
Option II	Retailer	2.41	63.35	54.25	**120.00**	0.61		-13	10	0nd	**5**	6
	Wholesaler	16.98	16.90	52.93	**86.81**	0.86		-23	42	1	**4**	5
	Manufacturer	39.21	9.07	54.68	**102.96**	0.92		-18nd	52	0nd	**-2nd**	3
	Total	**58.60**	**89.32**	**161.85**	**309.77**			**-19**	**20**	**0**	**2**	
Option III	Retailer	1.94	50.01	54.73	**106.68**	0.67		5nd	-4	0nd	**-2**	-1
	Wholesaler	12.90	12.56	54.26	**79.72**	0.89		3nd	-18	2	**-1**nd	-2
	Manufacturer	56.60	0.60	56.30	**113.50**	0.99		28	-109	-1	**13**	-1
	Total	**71.44**	**63.17**	**165.28**	**299.90**			**23**	**-8**	**0**	**4**	

nd indicates no significant difference at $p<0.05$

Table 4.6 Effect of ISL on supply chain performance

WM Effect (in %)								RWM Effect (in %)				
Option I	Retailer	3nd	-3	0nd	**-2**	-1		-150	28	0nd	**20**	8
	Wholesaler	12	-7	0nd	**-3**	-2		-298	71	0	**30**	22
	Manufacturer	67	-88	0	**13**	-4		28	57nd	0	**11**	3
	Total	**63**	**-6**	**0**	**1nd**			**5**	**41**	**0**	**21**	
Option II	Retailer	4	-3	0nd	**-1**	-1		-11	10	0nd	**5**	2
	Wholesaler	8	-12	0nd	**-1**	-1		-13nd	39	1	**6**	5
	Manufacturer	34	-73	2	**7**	-5		35	-16	-1	**11**	-1
	Total	**25**	**-12**	**1**	**2**			**19**	**13**	**0**	**7**	
Option III	Retailer	12	-15	0nd	**-7**	-3		7	-7	0nd	**-3**	-1
	Wholesaler	19	-63	0nd	**-7**	-6		9	-29	2	**-2**	-3
	Manufacturer	76	-2656	2	**25**	-14		58	-725	-3	**24**	-4
	Total	**64**	**-49**	**1**	**5**			**48**	**-18**	**0**	**7**	

nd indicates no significant difference at $p<0.05$

Table 4-6 Continued

Again, a negative value for the fractional change indicates that the cost under the information sharing mode is higher than under NI mode which is reflective of a poorer performance on the part of integrated mode and vice versa. A negative value for the fill rate difference is indicative of a poorer performance on the part of the integrated mode and vice versa. Therefore using Table 4.6, the ISL effect on individual performance is discussed in the following subsections.

4.4.3.1 RW-effect on supply agent individual performance

In a three tier supply chain, under option I scenario, integration between a retailer and its wholesaler would result in a 10% improvement in total supply chain cost performance which comes from significant reduction in manufacturer holding cost and retailer and wholesaler's backlog cost with the reduction in backlog cost contributing the most. According to the t-test analysis for significance, RW in an option I scenario has significant positive effect on the retailer's and the wholesaler's operating cost performance while it does not have a significant effect on the manufacturer's performance although the cost increase was 3%. Therefore the retailer and wholesaler can look for ways to incentivise the manufacturer perhaps by absorbing some of the manufacturer's backlog cost.

For the option II scenario, the effect of RW on a supply chain that uses the optimal EOQ policy (option II) is that the holding cost is increased for all supply members unlike the base stock policy (option I) where the increase is at the manufacturer tier only. However, the general observation for the retailer is that the backlog cost is significantly higher than its holding cost and the backlog cost of the wholesaler and the manufacturer. Since the overall reduction in backlog cost outweighs the overall increase in holding cost, the resultant effect of RW in a supply chain with optimal EOQ policy (option II) is 2% reduction in total supply chain cost which is statistically significant at $p<0.05$. However, like the observation with option I, the effect of RW under option II on the manufacturer is a 2% increase in total operating cost which is not significant at $p<0.05$. This increase in largely due to the effect of the holding cost as the 18% increase in holding cost has greater effect than the 52% reduction in backlog cost. Therefore the incentive to have or maintain a RW supply chain to the manufacturer would be to share the increase in holding cost with the

retailer and the wholesaler or not at all since the increase in cost is not statistically significant.

Under option III, the manufacturer is able to experience a reduced total operating cost in the RW mode to the tune of approximately 13%. This is a different observation compared to option I and II where RW effect was somewhat negative. The retailer and wholesaler this time around observed a 2% and 1% increase in total operating cost respectively, both statistically significant at $p<0.05$. Therefore the effect of sharing information between the retailer and the wholesaler only without including the manufacturer in a supply chain using option III is a 4% reduction in total supply chain operating cost, although the retailer and wholesaler are worse off individually. If the RW mode is to be maintained, then incentives should go to the retailer and the wholesaler, perhaps the manufacturer can share or absorb their increased cost.

It is clear from the results that benefits can be derived by all when RW is chosen provided incentive is provided to the non-benefiting counterpart.

4.4.3.2 WM-effect on supply agent individual performance

From Table 4.6, in option I scenario, the manufacturer was able to take advantage of the wholesaler's inventory information with a 13% improvement in daily average operating cost while the retailer and wholesaler are 2% and 3% worse off respectively. The overall 1% better performance experienced by the chain is of course due to the effect of the improved manufacturer's performance. For such a supply chain the wholesaler and the retailer would be better off being in a decentralised supply chain (NI mode). However since the benefit derived by the manufacturer is larger than the cost increase at the retailer and wholesaler, the incentive would be for the manufacturer to absorb some of those costs if the retailer and wholesaler are to agree on this information sharing mode.

Under option II, the observed effect of WM on supply chain using the Optimal EOQ model (option II) is a consistent reduction in holding cost across all tiers of the chain and a commensurate increase in backlog cost across the board. On the individual note, the retailer and wholesaler both experienced a 1% increase in operating cost while the manufacturer benefited with a 7% reduction in operating cost. Again, the

incentive for such collaboration between wholesaler and manufacturer would be for the manufacturer to absorb some of the cost of the other two.

As for the option III scenario, effectively there was a 5% improvement in the total supply chain operating cost solely due to the magnitude of the reduction in supply chain daily average holding cost of which the manufacturer was the biggest contributor. From the perspective of the supply chain agents, the retailer and wholesaler both experienced 7% increase in daily operating cost compared to the NI mode while the manufacturer benefited with a 25% reduction in daily operating cost. Again the manufacturer can incentivise the wholesaler and the retailer by absorbing some or all of their cost increase.

Looking at the various observations under WM effect, there are certain inferences that can be drawn.

- The manufacturer appears to be the only beneficiary of such integration and this benefit comes mainly in the holding cost reduction.
- Examining the performance of individual members, the retailer and wholesaler are better off in a decentralised supply chain but the benefit of WM to the manufacturer means that they can operate at similar levels or even better as long as they receive good incentives from the manufacturer.
- In summary one can see that the 'WM-option III' combination is more serving than the other options.

4.4.3.3 RWM-effect on supply agent individual performance

For option I scenario, the daily average total operating cost of the retailer and wholesaler was reduced by 20% and 30% respectively. This improvement was singularly as a result of the significant reduction in backlog cost, as the respective average holding cost was increased and the average ordering cost was unchanged. The manufacturer on the other hand experienced lesser holding cost and backlog cost compared to that of the NI mode. This observation appear contrary to the general observation under the other levels of integration where a decrease in holding cost is accompanied by a decrease in fill rate performance and an increase in backlog cost. The reason for this is perhaps due to the fact that the manufacturer was using the inventory position of the retailer and wholesaler in deciding when to order and what quantity to order thereby creating an optimal effect that led to reduction in both

costs. To explain it better the result in WM mode is compared with that of the RWM mode. In the WM mode the manufacturer's decision is based only on the wholesaler's inventory information and retailer's order information. In contrast, the manufacturer's decision in the RWM mode is based on the inventory position of the wholesaler and the retailer as well as real time demand information. The effect of this change sees the daily average holding cost in the WM mode rise from approximately £8 to £18 in the RWM mode. This rise in holding cost resulted in a reduction in backlog cost from approximately $10 in WM to $2 in RWM. Therefore, intrinsically, the observation remains true that holding cost rise result in backlog cost reduction and vice versa. Overall, there was marked improvement in cost performance for all agents in the RWM mode under ordering option I with the reduction in backlog cost being the sole contributor.

For Option II, the retailer and wholesaler both saw a rise in holding cost and an expected fall in daily average backlog cost. As anticipated, the fill rate was better than the NI mode but same for the RW counterpart. For the manufacturer, the story changes as the holding cost was reduced by 35% while the backlog increased by 16% in comparison to the NI mode. In summary, the retailer and wholesaler saw a rise in holding cost and fill rate with a fall in backlog cost, resulting in a 5% and 6% decrease in daily average operating cost respectively. The manufacturer was the biggest beneficiary with 11% reduction in daily average operating cost. Overall, the supply chain operating cost saw a 7% improvement in total cost performance.

For Option III, due to the larger effect of the holding cost reduction over backlog cost increase, the overall supply chain operating cost was improved by 7%. However the individual performance of the retailer and the wholesaler was worse off by 3% and 2% respectively. The manufacturer on the other hand saw a 24% improvement in cost performance of which the improvement in manufacturer's holding cost played the most part and this was solely responsible for the improved overall supply chain performance. For RWM to be acceptable to the retailer and the wholesaler, the manufacturer has to provide incentives to them by absorbing their cost increase or by any other means that will serve to protect them from this cost increase.

On the one hand, under the RWM mode, the retailer and the wholesaler observed an increase in holding cost and a decrease in backlog cost which resulted in an

improvement in daily total average operating cost in the option I and II scenarios. Their fill rate was also improved under these two scenarios. Their performance was worse off under the option III scenario. However, of the three ordering options, the retailer experienced the least cost performance under option III while it was option I for the wholesaler. The manufacturer on the other hand saw a decrease in holding cost and an increase in backlog cost which resulted in an improvement in daily total average operating cost in the option II and Option III scenarios. However, under the option I scenario, the manufacturer saw a decrease in backlog cost instead of an anticipated increase. The reason for this has been explained earlier and this resulted in an improvement in operating cost which also represents the scenario where the operating cost of the manufacturer was least. In summary, the manufacturer benefits from RWM integration under all three ordering policies but the retailer and wholesaler only benefit under option I and II.

4.4.3.4 General effect of information sharing adoption

It is clear from the result that all three levels of integration would benefit the supply chain as a whole but not beneficial to everyone concerned. Some benefit more than others while in some cases, some do not benefit. The level of benefit, if any, is dependent on the ordering policy of choice. The retailer and wholesaler appear to have a worse performance under option III for all integration modes but they do well under policies I and II with the exception of WM integration type. The manufacturer on the other hand performs better under all integration forms but does particularly well under option III. The greater performance of the manufacturer under option III, contrary to what is obtainable at the retailer and wholesaler, actually improves the overall supply chain performance significantly better than under the other two policies. Therefore for a supply chain using ordering policy III, the incentive to adopt any level of integration would have to be provided by the manufacturer. Looking at the various combinations of integration and ordering policies, the supply chain state with the least cost performance is the RWM and option III combination.

4.4.4 Summary of Findings and Discussion

This section provides the answer to Question 1e:

Question 1e: *How does varying the level of information alone affect the performance of the three ordering policies mentioned?*

From the control theory perspective, engaging in information sharing does not change the nature of bullwhip effect for options I and II. The order amplification is kept at the minimum under option I and option II consistently experienced partial bullwhip effect under all three information sharing modes (RW, WM and RWM). However the stabilising effect of the wholesaler under option II is particularly higher under RW and RWM modes. Also the nature of the bullwhip effect in option III is changed from being consistent in the NI mode to being partial under RW and RWM modes. RW and RWM mode have one thing in common, the wholesaler is privy to market demand information and uses this real time information in its inventory decisions. It is therefore concluded that:

- The stabilising effect of the wholesaler is more pronounced when the wholesaler using a batch ordering policy (e.g. optimal EOQ model) or a combined batch-and-parameter based ordering (e.g. modified base stock policy) is privy to, and uses, actual demand information.

The general effect of information sharing on the ordering pattern of the supply chain agents using the shared information is an increase in the effective average order quantity (EAOQ) and a commensurate increase in ordering rate (OR). There is no apparent effect on the ordering pattern of any of the supply agents when the ordering policy is the parameter based policy (Base stock policy-option I), and regardless of the type of ordering policy, the retailer's ordering pattern is not affected by all three information sharing modes. Therefore, from the result, one can infer the following:

- Under the batch or combined batch-and-parameter based models, users of downstream inventory information should revisit their shipping strategy to adopt one that favours more order quantity placed less frequently while supply chains using the parameter based policy (base stock policy) need not change their shipping strategy when considering information sharing at any level.

At the supply chain level, a supply chain with the base stock policy (option I) only benefits from information sharing when the wholesaler and/or the manufacturer uses retailer's inventory information (which includes the market demand information). However the supply chain obtains benefit regardless of the mode of information sharing (RW, WM or RWM) under a batch or combined batch-and-parameter based

ordering policy. Interestingly, RW and RWM favours option I more than the other two policies while WM mode favours option III more.

A summary of the effect of adopting various information sharing strategies on individual supply agent and the supply chain as a whole is shown in Table 4.7.

	Option I			Option II			Option III		
	RW	WM	RWM	RW	WM	RWM	RW	WM	RWM
Retailer	>	<	>	>	<	>	<	<	<
Wholesaler	>	<	>	>	<	>	<	-	<
Manufacturer	-	>	>	-	>	>	>	>	>
Supply Chain	>	-	>	>	>	>	>	>	>
Acceptable?	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Incentivisation?	No	No	No	No	Yes	No	Yes	Yes	Yes
Incentive to?	None	None	None	None	R,W	None	R,W	R,W	R,W

Beneficial effect (>), no significant effect (-), detrimental effect (<)

Table 4.7 Effect and motivation for information sharing adoption

The following conclusions are drawn:

- The RW strategy can be adopted in option I and II scenarios without any consideration for giving incentives to non-benefiting members. However, in the option III scenario, RW can still be adopted but the responsibility of incentive giving lies with the manufacturer.
- The WM strategy is not likely to be acceptable by the retailer and wholesaler as the overall benefit of the strategy is not large enough to incentivise both the retailer and wholesaler for option I while the manufacturer would have to incentivise both downstream agents under option II and III for the WM strategy to be acceptable.
- The RWM strategy is completely acceptable by all supply chain agents and no incentivisation is required under option I and II scenarios. However, under

option III, the retailer and wholesaler are less inclined to adopt RWM strategy unless the manufacturer can provide certain incentives to justify their involvement.

The observations and implications of the result discussed in sections 4.2 and 4.3 is only applicable under a non-information sharing scenario. The observations for the various ISL in section 4.4 is only applicable in a serial supply chain structure. However when the supply chain engages in information sharing, regardless of the information sharing level (ISL), the implication to the supply chain in section 4.4 does not hold true for all supply chain structure scenario under each ordering option. This is because each structure provides benefit to certain supply chain agents and do not favour others. This has been discussed in section 4.3. In the same light various ISLs provide benefit to some agents and not others and the level of benefit depends on the ordering option of choice. This has also been discussed in section 4.4. Therefore one observes a cancellation, repelling, corroborating or worsening of effect on individual agent's performance when the ISL effect is superimposed on the structure effect. The cancellation and repelling effect can either be positive or negative. Positive cancellation (CA+) means the resultant effect is beneficial produced from a positive ISL and negative Structure or a negative ISL and a positive Structure effect. A negative cancellation (CA-) occurs when the resultant effect is negative produced either from a positive ISL and negative Structure effect or vice versa. A negative repelling effect (R-) occurs when the positive effect of both ISL and Structure produces a resultant negative effect. On the other hand a positive repelling effect (R+) occurs when the negative effect of both ISL and Structure produces a resultant positive effect. Worsening effect (W) is generated when the resultant effect is negative which is produced from both negative ISL and Structure effects and a corroborating effect (CO) is felt when the resultant effect is positive produced from a positive ISL and a positive Structure effect.

4.5 INTERACTION BETWEEN THE INTEGRATION EFFECT AND STRUCTURE EFFECT

The relative performance of each supply chain agent under each integration mode for all four supply chain structures is assessed here. The idea for this comparison is to show whether the interaction between the integration effect and the structure effect is

beneficial or detrimental to the performance of the supply chain as measured by the magnitude of the percentage change. Therefore it might be wise, considering certain ordering policies, to engage in one and not the other or engage in both to reap greater benefits. The relative performance of the integration mode to the non-integrated mode for each structure is derived by computing the difference between the cost performances of each structure in the integration mode to that of the NI mode from Table 4.1. This difference is then expressed as a percentage of the NI-base model performance. In other words the difference between the performance of the structures in all the integration mode and the NI-base model is divided by the performance of the NI-base model. The result of this computation can be found in Appendix 4.4. A positive value reveals that the effect is beneficial while a negative value indicates a detrimental effect on cost performance. From the table, the first three rows show a summary of the singular effect of restructuring from a non-integrated serial structure (base model) to WH, MF and NT structures and the next three rows summarises the singular effect of information sharing when a non-integrated serial structure (base model) engages in RW, WM and RWM integration modes respectively. The next set of rows summarises the effect of jointly engaging in information sharing and restructuring.

The nature of interaction effect of each integration level with each structure is depicted with the following symbols CO, CA+, CA-, R+, R- and W, and is also shown in Appendix 4.4. These have been defined earlier in the last paragraph of section 4.4.4 and are descriptive of the nature of the interaction effect but ultimately the interest lies in whether the interaction effect is beneficial or not. The CO, CA+, and R+ symbols are all beneficial effects but CA-, R- and W are all detrimental to supply chain cost performance.

The main decision framework for combining any ISL strategy with any supply chain reconfiguration strategy is shown in Figure 4.2. Whatever the decision is, it is also important to know where the need for incentives lie. Consequently the decision summary is shown in Table 4.8 for each combination of ISL and supply chain structure. Symbol R in the table represents the retailer while W and M represent the wholesaler and manufacturer respectively. The subsequent sections 4.5.1, 4.5.2, 4.5.3 summarises the answer to Question 1f.

Question 1f: *What is the interaction effect of supply chain structure and information sharing level on batch ordering, parameter based and the combined ordering policies?*

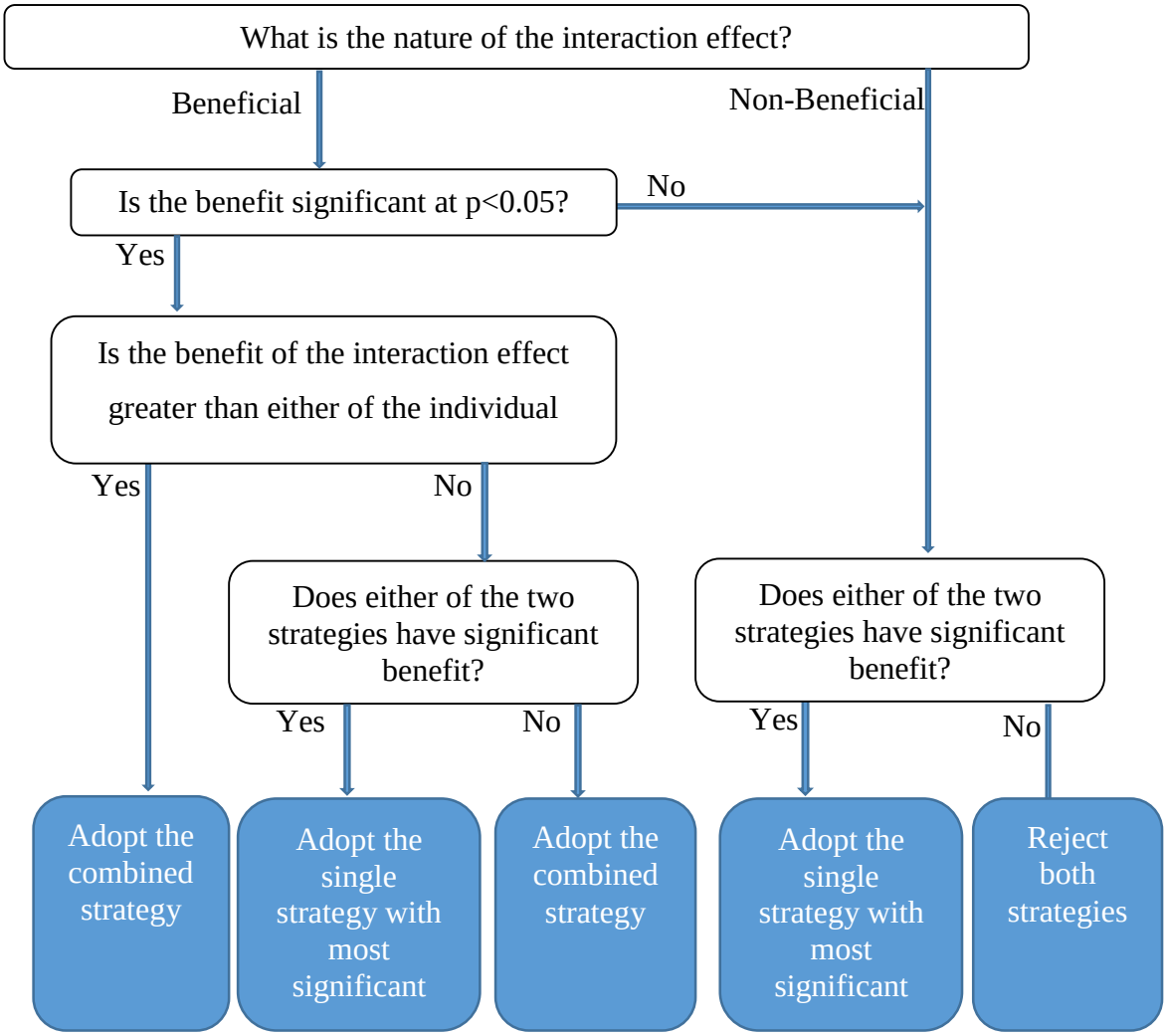


Figure 4.2 Combined strategy acceptance decision framework in a non-breach scenario

		RW			WM			RWM		
		WH	MF	NT	WH	MF	NT	WH	MF	NT
Option I	Interaction effect	CO	CO	CA+	CO	CO	CA+	CO	CO	CA+
	Significant?	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes
	Acceptable?	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes
	Alternative	-	-	RW	NI	NI	NI	-	-	RWM
	Incentive to?	M	M	-	-	-	-	-	-	-
Option II	Interaction effect	CO	CO	R-	CO	CO	CO	CO	CO	R-
	Significant?	Yes	Yes	No	Yes	No	Yes	Yes	Yes	No
	Acceptable?	No	Yes	No	Yes	No	No	Yes	Yes	No
	Alternative	WH	-	NT	-	MF	NT	-	-	RWM
	Incentive to?	R	R	R	R	W	R	-	R	-
Option III	Interaction effect	CO	CO	CO	CO	CO	CO	CO	CO	CO
	Significant?	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
	Acceptable?	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes
	Alternative	-	-	NT	-	WM	-	-	-	RWM
	Incentive to?	R	R,W	R	R	R,W	R,W	R	R,W	R,W

Table 4.8 Decision making for adopting ISL and supply reconfiguration as a worthwhile strategy

4.5.1 Interacting effect of ISL and supply chain structure under parameter based ordering policy

Under normal circumstances, the base stock policy does not enjoy a cost improvement benefit from structural simplification only, but the result in Appendix 4.4 shows that when any of these strategies is combined with an information sharing strategy that includes the retailer's inventory information (RW or RWM), the cost performance of base stock policy is improved, although incentive has to be given to the manufacturer under both RW and RWM information sharing strategy. The benefit of sharing retailer's information with the wholesaler and/or manufacturer alone is greater than the benefit of combining this strategy with the networking strategy, hence this combination is not acceptable. It is also apparent that the base stock policy will not benefit from WM information sharing strategy either alone or in combination with other structural reconfiguration strategies.

4.5.2 Interacting effect of ISL and supply chain structure under batch ordering policy

Under the batch ordering scheme such as the optimal EOQ model, the only acceptable interaction that does not require incentivisation is the one involving wholesaler simplification (WH) and full information sharing (RWM). The other situation where the combined or synergic benefit of information sharing strategy and structural reconfiguration is greater than the individual benefit is found under the following combinations; RW + MF; WM + WH; RWM + WH, and under these combinations, the retailer requires incentivisation.

4.5.3 Interacting effect of ISL and supply chain structure under batch-and-parameter based ordering policy

With the combined policy (option III), an information sharing strategy that includes sharing the retailer's inventory information with the wholesaler and/or manufacturer is not a good match with the networking strategy. The supply chain is better off either undertaking the network reconfiguration alone or undertaking the full information sharing strategy or combining networking reconfiguration with WM information sharing strategy. On the other hand, the wholesaling simplification strategy combines well with either RW or RWM with the retailer requiring incentivisation. The only time when information sharing between the wholesaler and

the manufacturer only produces a combined benefit is when the structural reconfiguration strategy is of the wholesaling simplification type.

4.6 DECISION MAKING FOR THE COMBINED IMPROVEMENT STRATEGIES

Having considered the performance of the supply chain under various ordering policies, integration levels and supply chain structures, the supply chain manager of course would be interested in knowing which scenarios represent the best option with the least cost performance. Given the same ordering option, if one must decide which integration level and structure to adopt, then the following recommendation is given in Table 4.9 based on the overall best performance. The scenario with the least average daily operating cost represents the best scenario amongst alternatives. As it is reasonable that two separate performance improvement strategies may be adopted one at a time, the other one adopted at a later time in the future, the ideal thing would be to select the best alternative in each improvement category. The supply chain may decide to select the best structural reconfiguration alternative first and then the best information sharing strategy later in the future or vice versa. However this stepwise adoption of the two best alternatives in their respective categories may not ultimately produce the best cost performance in the long run. It is therefore important to know which combination of information sharing and structural reconfiguration represents the best option in the long run and then perhaps adopt that combination in a step wise manner.

For instance Table 4.9 clearly shows that for a parameter based policy such as the base stock policy, the two best options amongst alternatives are manufacturing simplification and full information sharing. The adoption of both strategies, either stepwise or at once, would produce a positive synergic effect more beneficial than their respective individual performances. Although the best synergy for the parameter based policy comes under the combination of full integration and wholesaling simplification strategies, this performance is only 0.1% better off which is not significant at $p<0.05$. Therefore the supply chain using the base stock policy may still go ahead with the original option of full information sharing and manufacturing simplification as this is the better option if stepwise adoption is considered. Clearly for the batch ordering policy such as the optimal EOQ model,

although the individual best performance comes under networking and full integration separately, the best option on the long run would be the combination of manufacturing simplification and full integration strategies as the performance here is 11.3% better than the original option. Under the combined policy mode, the decision would be to adopt both wholesaling simplification and information sharing between the wholesaler and the manufacturer only as opposed to the full information sharing strategy because of the significant 1.3 % improvement in performance.

	Structure	ISL	Good synergy?	Best Alternative	% difference	Decision
Option I	MF	RWM	Yes	RWM+WH	0.1%nd	RWM +MF
Option II	NT	RWM	No	RWM+MF	11.3%	RWM+MF
Option III	WH	RWM	Yes	WM+WH	1.3%	WM+WH

Table 4.9 Decision making for combined strategies under each ordering policy

4.6 CONCLUSION

This study has corroborated the assertion that incorporating strategies to reduce the bullwhip effect does not necessarily constitute improvement in supply chain cost performance as previously established by Chen and Samroengraja (2004). In fact, as the results suggest, the policy with the lowest bullwhip effect (option I- parameter based ordering policy) has higher supply chain cost than that with higher bullwhip effect (option II- batch ordering policy). In addition, the study included the wholesaler tier in the simulation modelling, which was not included in Chen and Samroengraja (2004), and found evidence to support the claim of Baganha and Cohen (1998) that the wholesaler has a stabilising effect on bullwhip effect but this claim **does not always apply**, at least, to the combined batch-and-parameter based policy type (option III).

The results also suggest that a policy with a higher ordering rate (OR) and lower EAOQ (Case-2) performs better than a policy with lower OR and higher EAOQ (Case-1) under normal circumstances, but there exists a point along the continuum between Case-1 and Case-2 where performance is optimal (or at least near optimal).

In summary, this study has substantiated the argument that the direction and magnitude of benefit derived from information sharing will depend on the operating

condition of the supply chain (ordering policy and supply chain structure) and each tier of the supply chain is affected differently. This study has also shown that, since ISL and structural reconfiguration are both supply chain improvement strategies, both can be adopted at once or in a piece meal manner. However piece meal adoption needs to be carefully considered as the synergy of the two improvement strategies may have a less beneficial effect or even a negative effect altogether.

Effectively, under the parameter based policy, a piecemeal adoption can either start with full information sharing and then manufacturing simplification or vice versa but preferably the former. However, under the batch ordering system, the piecemeal adoption should start with full information sharing and then manufacturing simplification. On the other hand, under the combined policy, the wholesaling simplification strategy should be adopted first and then the sharing between the wholesaler and the manufacturer alone.

4.6.1 Managerial Implication

Information sharing, be it full (RWM) or partial (RW or WM), is not always beneficial to the supply chain and some members are even worse off than when information was not shared. The benefit of course is determined by the ordering policy of choice and the structure of the supply chain, as this study has shown. In a decentralised supply chain where each tier or agent in each tier has autonomy over its decisions and can decide to share information with the upstream agent in order to improve its own operation, it is particularly important for supply chain managers to know how such information sharing affects them even if they are not directly involved in the sharing. This knowledge is key so as to be able to demand for incentives if such information strategy has a detrimental effect on one's operation. Therefore the implementation of any information sharing strategy should be fully assessed (especially for non-participating members) before undertaking it at any level.

There has been recent call for simplifying the supply chain as the growing level of interdependence between organisations, especially in a supply chain setting, is becoming increasingly problematic for effective management. Supply chain managers should also bear in mind the effect of structural improvement in the supply chain and how the benefit of any current information sharing strategy might be

affected as this study has shown that under certain ordering policies, some supply structures do not combine well with certain information sharing strategies.

4.6.2 Need for Further Research

The decisions made in this chapter might be premature as the supply chain is subject to disruption and when this occurs the anticipated benefit may no longer be viable. Therefore what was perceived to be an optimal supply chain scenario may not be in the face of a disruption. It was necessary to conduct the experiments in the non-breach scenario (as done in this chapter) so that the impact of information security breach can be assessed by comparing this to the performance in the breach scenarios. The next study therefore takes a look at the impact of disruptions caused by information security breach on supply chain performance and includes this in the final decision making. The next chapter critically examines this to see how the anticipated benefit of information sharing or supply chain restructuring diminishes or is validated under information security breach disruption.

Chapter 5 THE IMPACT OF INFORMATION SECURITY BREACH

5.1 INTRODUCTION

It has been established in the previous chapter that under a non-breach scenario, two types of strategies: supply chain structural reconfiguration strategies and information sharing strategies, hold benefit to the supply chain depending on the ordering policy of choice. These two strategies have been dubbed improvement strategies but this has been examined under normal circumstances i.e. no disruption. However, in most real life operations, disruption is inevitable and it is still not clear from past literature how the landscape of the benefit of either or both improvement strategies changes in the face of disruption. It is therefore imperative that the evaluation of these two improvement strategies be done with consideration for the impact of such disruptions.

The flow of information within the supply chain is crucial to the timely flow of materials across the supply chain. Any disruption in this flow of information would create a disruption in the flow of materials and hence have an impact on performance of the supply chain. Information security breach causes disruption in the flow of information and this is increasingly inevitable as the level of sophistication and depth of perpetration is known to increase year in year out. This study therefore aims to establish the nature of the impact of information security breach on supply chain performance under the scenarios established in the previous chapter. This study posits that the assessment of the impact of information security breach may ultimately affect the proclivity of the supply chain to adopt some of the promising improvement strategies discussed in the previous chapter.

5.1.2 Research Motivation and Research Questions

The magnitude and direction[4] of breach impact would depend on the nature of the breach, hereafter called breach profile, and the type of ordering policy being used in the supply chain. The profile of a breach is conceptualised in this thesis as the level of frequency of occurrence (RoC) of the breach and the severity/disruption duration of the breach when it occurs. A less disruptive but less recurring breach is

[4] Direction refers to whether the effect is positive or negative.

classified as having a breach profile 1 (BP1). From Table 3.2 in section 3.4.1, it is clear that IBMS and PT belong to this class. A less disruptive but highly recurring breach is termed breach profile 2 (BP2) with AOW a very good example, while a highly disruptive but less recurring breach is classified as breach profile 3 (BP3) with SFDD a very good example, shown previously in Table 3.2. Generally BP1 and BP2 are classified as less disruptive breaches but BP2 is typically a highly recurring breach. On the other hand BP3 is also classified as a highly disruptive breach. These three profiles would affect the supply chain in different ways but this has not been established in past literature.

First this chapter examines the level of impact information security breach has on supply chain performance and then evaluates how the impact of a breach at one end of the supply chain is transmitted to members of the same supply chain existing in upstream end. The transmission of impact is called the reverberating effect of the breach. This is defined as the condition where the breach occurring at the downstream negatively impacts the performance of supply agents as one goes upstream. The question here is;

Question 2: Does the impact of information security breach increase or decrease as one goes upstream?

Secondly, this chapter evaluates how the RoC level and the disruption duration level of the breach affect supply chain performance at an operational level (individual agent performances) and a strategic level (supply chain performance). Hence the following question:

Question 3: What is the effect of increasing the RoC or disruption duration from low to high on the impact a breach has on supply chain performance?

This knowledge is also important in order to efficiently and effectively incorporate the right risk management measures and to have them at the appropriate levels. Risk management measures cover three main aspects: prevention & deterrence; detection & recovery, and corrective measures. Disruption duration is a function of level of security breach corrective measures (otherwise called mitigation measures) and RoC is indicative of the required level of security breach prevention & deterrence measures (otherwise called prevention measures). Therefore if a change in disruption duration from low to high have greater negative effect than that of RoC for any

supply chain scenario, then IT priority would be on corrective measures, otherwise the priority would be prevention & deterrence.

Thirdly, this chapter examines whether the improvement strategies (structural reconfiguration and information sharing) prescribed in the previous chapter can benefit the supply chain in a breach scenario.

Question 4: Are the improvement strategies beneficial to the supply chain especially under disruption brought about by information security breach?

The best solution to avoiding or reducing the impact of information security breach of course would be to have appropriate levels of prevention and deterrence; detective and recovery, and corrective measures. However, if an improvement strategy or combination of improvement strategies is found to reduce the impact of a breach on the base model, then such strategy or combination of strategies is said to have a mitigating effect and can be used as a breach impact reduction (or mitigation) strategy. If this impact is made worse, however, such strategy or combination of strategies is considered to have an exacerbating effect. If no effect on the impact is observed then the effect is said to be of the stabilising type.

5.1.1 Nature of Breach Occurrence

The knowledge of how each ordering policy, structure and information sharing scenario are impacted by each breach profile and the extent of the impact to all agents in the supply chain is crucial to the formation or fostering of any supply chain partnership. It has not been shown which ordering policy would be most resilient[5] to security breach and which one would be the best cost performer under various breach circumstances. It is also not fully known how various operating conditions mitigate this impact.

It is important to keep in mind that the assumption in our model is that when a security breach occurs at the retailer's end, the information system that allows customers to place demand becomes unavailable and the breach disruption duration represents the amount of time it takes to rectify the problem caused by the breach.

[5] Most resilient here means least affected by security breach impact in terms of percentage increase in operating cost.

The assumption is that the end customer waits till the retailer's system is restored and places it demand. Therefore demand is not actually lost during the disruption period but only delayed. During this period the retailer is unable to know what the actual demand would be. The retailer then assumes the demand for that day is zero but continues to forecast demand based on moving average forecasting technique. It is important to state at this juncture that the cost being investigated in this study are those directly related to inventory management and not to other functions in the business. Therefore the total cost of information security breach may be significantly higher than those mentioned here. This is one of the scope and limitation of the research.

5.1.3 Structure of This Chapter

The rest of this chapter is sequenced as follows. Section 5.2 discusses the anatomy of a security breach using the serial supply chain scenario with no information sharing (also called the base model) for all three ordering options. Subsequently, the breach mitigating, exacerbating and stabilising effect (MES effect) of restructuring from a serial structure to the other structure types alone is examined in 5.3 and the MES effect of the various information sharing levels alone is evaluated in 5.4. Section 5.5 then examines how the interaction effect of structure and ISL mitigates, exacerbates or stabilises the impact of security breach.

5.2 ANATOMY OF A BREACH IMPACT

To start with, this study aims to understand how each ordering policy responds to security breach impact. To estimate the impact of information security breach for each ordering policy, the performance in the non-breach scenario (in chapter 4) is compared to the performance in the breach scenario. First, the difference between the cost performance in the breach scenario and the non-breach scenario is calculated and expressed as a percentage of the cost performance in the non-breach scenario. However the impact of breach on the fill rate performance is taken directly as the difference between fill rate performance in breach scenario and the non-breach scenario and not expressed as a fraction of non-breach scenario performance.

The percentage difference is termed 'breach impact' and the direction of the breach impact can be of a positive type or a negative one. A negative value reveals that the cost in the breach scenario is higher than that of the corresponding non-breach state

indicating that a poorer performance occurs when there is a breach while a positive value indicates a better performance when breach occurs.

This impact is tested for significance at $p<0.05$. The reason for this test is to show whether breach impact is statistically significant at $p<0.05$ or not. If the magnitude of the breach impact is not statistically significant at $p<0.05$, then the breach impact is said to be non-existent and this is identified with superscript 'nd'. Otherwise the breach impact is said to be existent and significant. The breach impact on each supply agent for each of its performance measures (daily average holding, backlog, ordering costs and fill rate) and that on the entire supply chain is computed for each ordering policy under the serial non-information sharing scenario, the base model.

The impact of all four information security breaches on the base model under each ordering policy is shown in Figure 5.1. It is clear from Figure 5.1 that the various information security breaches have varying impact on the supply chain depending on the profile of the breach and the ordering policy being used in the chain.

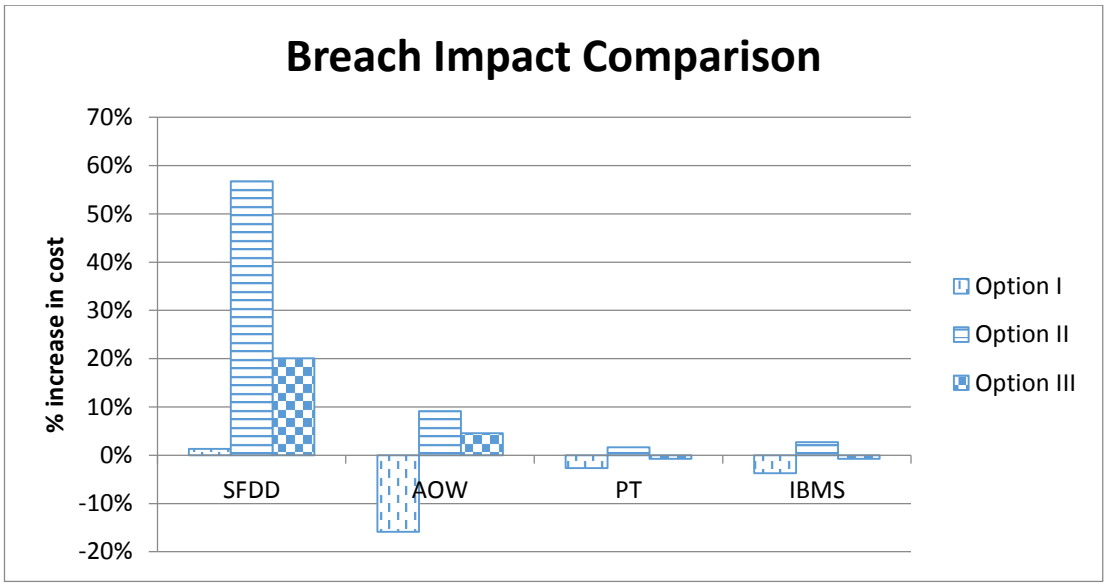


Figure 5.1 Effect of ordering option on breach impact on supply chain with no integration

Recall System Failure and Data Destruction (SFDD), Attack on The Web (AOW), Infection by Malicious Software (IBMS) and Physical Theft (PT) are the four information security breach being studied. SFDD (BP3) appear to increase the operating cost for all ordering options while AOW (BP2), IBMS (BP1) and PT (BP1) actually decreases the supply chain daily average operating cost under options I and III while that of option II is increased.

The reason for the above observation requires further analysis. Therefore, the analysis will start with an examination of how the ordering pattern of each policy is changed to cope with the effect of the breach profile which is an indication of the flexibility of the policy to breach, defined here as 'breach resilience'. Then the effect of the breach profile on cost performance is examined to understand where risk management priorities lie. To understand the effect of the breach profile, one needs to know what the effect of increasing one element of the breach profile would be. In other words what is the effect of a high disruption duration or what is the effect of a high rate of occurrence (RoC)? BP1 has the same breach recurrence rate as BP3 but BP3 has significantly higher disruption duration than BP1. Hence the effect of having a higher Disruption duration can be assessed when you compare the impact of BP1 to that of BP3. In the same light BP1 has the same disruption duration with BP2 but BP2 has a significantly higher recurrence rate than BP1. Consequently the effect of having a higher recurrence rate can be assessed when the impact of BP2 is compared to that of BP1. IBMS and PT belongs to the BP1 category, although PT has a slightly higher RoC than IBMS. AOW and SFDD belong to BP2 and BP3 respectively.

5.2.1 Impact on Ordering Pattern

The change in ordering pattern is conceptualised as the change in ordering frequency and effective daily average order quantity. The change brought about by information security breach on the effective average order quantity (EAOQ) is calculated by taking the difference between the EAOQ in the breach state and the corresponding non-breach state and this is expressed as a percentage of the non-breach state. Since the ordering rate is originally measured in percentage, the difference due to information security breach is computed as is and not expressed as a percentage of the non-breach state. The result of this computation for the parameter based ordering policy (option I), batch ordering policy (option II) and batch-and-parameter based policy (option III) is shown in Table 5.1, 5.2, 5.3 respectively. The original values for each supply agent in the non-breach state is included in the first row in each table. The changes to the original values brought about by each security breach (measured in percentage) is included in the subsequent rows and labelled accordingly.

OPTION I						
	Retailer		Wholesaler		Manufacturer	
	OR %	EAOQ	OR %	EAOQ	OR %	EAOQ
NB	100	9.98	100	9.97	100	9.94
	Breach Impact					
AOW	19.97	-25.01%	19.97	-25.14%	19.97	-25.02%
IBMS	1.28	-1.30%	1.28	-1.31%	1.28	-1.32%
PT	1.99	-2.04%	1.99	-2.06%	1.99	-2.07%
SFDD	6.40	-6.89%	6.40	-7.00%	6.40	-7.05%

Table 5.1 Effect of security breach on the ordering pattern of the base stock policy (option I)

	OPTION II					
	Retailer		Wholesaler		Manufacturer	
	OR %	EAOQ	OR %	EAOQ	OR %	EAOQ
NB	89	11.28	62	16.00	49	20.36
	Breach Impact					
AOW	0.03	0.02%	0.04	0.01%	-0.04	0.14%
IBMS	0.00	0.00%	-0.01	0.00%	-0.03	0.02%
PT	0.00	-0.01%	-0.01	0.00%	-0.02	0.01%
SFDD	0.29	-0.01%	0.08	0.21%	0.01	0.35%

Table 5.2 Effect of Security breach on Option II ordering pattern

	OPTION III					
	Retailer		Wholesaler		Manufacturer	
	OR %	EAOQ	OR %	EAOQ	OR %	EAOQ
NB	98	10.18	89	11.16	67	14.81
	Breach Impact					
AOW	19.24	-24.46%	15.98	-21.95	9.04%	-15.66
IBMS	1.17	-1.21%	0.93	-1.07	0.61%	-0.94
PT	1.86	-1.95%	1.50	-1.73	0.87%	-1.35
SFDD	6.28	-6.89%	5.74	-7.01	4.33%	-7.10

Table 5.3 Effect of security breach on Option III ordering pattern

5.2.1.1 Parameter based ordering policy (option I)

The dynamic nature of the parameter based policy such as the base stock policy (option I) where the order quantity can be large or small depending on the how far the inventory position is from the order-up-to level makes it a very flexible policy to uncertainties as suggested by the low bullwhip effect discussed in the previous

chapter. The ordering pattern is changed to cope with the effect of security breach whereby order quantity is increased to cope with the sudden demand increase that the breach creates (recall the assumption in section 5.1.2), which then results in lower ordering rate. From Table 5.1, one can see that there is a noticeable change in ordering pattern of all supply chain agents due to the influence of a security breach. An interesting observation here is that the increase in ordering rate and effective order quantity is similar for all members despite the fact that the breach occurred at the retailer. This shows that a breach regardless of its profile has a consistent reverberating effect on the ordering pattern for all associated supply chain agent using parameter based ordering (base stock policy). Examining the effect a breach with high RoC would have on the ordering pattern is done by comparing the effect of BP1 (low RoC) to BP2 (High RoC) and that of disruption duration is done by comparing the effect of BP1 (low disruption duration) to BP2 (high disruption duration). This examination shows that both disruption duration and RoC of a breach have the same effect on the ordering pattern of the parameter based ordering policy but the magnitude of effect of RoC is greater.

5.2.1.2 Batch ordering policy (option II)

In contrast to the effect of security breach under the base stock policy (option I), the ordering pattern of the supply chain using optimal EOQ model (option II) appear to be unperturbed to a large extent by the breaches as shown in Table 5.2. There seems to be negligible alteration in the pattern with which supply chain agents place their orders. In other words the reaction of batch ordering policy to security breach is minimal or non-existent and as such little or no flexibility is inherent in it. In addition there is no apparent breach reverberating effect on the ordering pattern of supply agents as one goes upstream the chain. It is also evident that higher RoC and disruption duration have no effect on ordering pattern.

5.2.1.3 Combined batch-and-parameter based policy (option III)

The effect of security breach on the ordering pattern of the retailer using option III is similar to that produced in option I. However the reverberating effect to the wholesaler and the manufacturer tells a different story and this is shown in Table 5.3. Common trends emerge for all security breach type. Like option I, the change in ordering pattern here shows the flexibility inherent in option III. Unlike option I where the same change occurred throughout the supply chain, the percentage change

in ordering pattern (i.e. the ordering rate and the effective order quantity) decreases as you go upstream. Higher RoC and higher disruption duration produces bigger changes in ordering pattern with RoC having the greater effect. This seems plausible as the order size in option III is determined by how far the inventory position is from the re-order point and a simple economic order quantity is included. Just like option I, option III ensures to bring the inventory position back to the desired position as quickly as possible but with an additional EOQ giving it a better capacity to respond to increased demand. It is to be reminded that the EOQ calculation here is simplistic (i.e. one batch) and not optimal like option II (2.236 batches). Therefore, option III combines the flexibility of option I and the advantage of bigger order quantity of option II. Judging from the level of change produced by option III in response to the security breaches, one could infer that the ordering policy has some resilience. However, since the change in ordering pattern is lesser in magnitude to that of option I, one would expect that the level of security breach resilience would be less than that of option I. An analysis of the cost impact would serve to confirm this supposition.

5.2.2 Impact on Cost Performance

The impact of security breach for each ordering option is computed as described in the opening paragraph of section 5.2 and shown in the subsequent tables for the various ordering options. The tables include the result of the performance in a non-breach scenario which is labelled ‘No breach’ and the impact of each breach type is labelled accordingly.

5.2.2.1 Parameter based ordering policy

Since the base stock policy inherently increases the order quantity and reduces the ordering frequency to cope with the security breach effect, one would expect a proportional decrease in daily average ordering cost. This is because a decrease in ordering frequency decreases the total fixed ordering cost which should result in a decrease in daily average ordering cost. This is confirmed in Table 5.4 as there was a 2% (AOW), 1% (SFDD), 0.22% (PT), and 0.14% (IBMS) reduction in daily average ordering cost respectively. This order coincides with the order of ordering rate reduction AOW>SFDD>PT>IBMS. Those of PT and IBMS approximates to zero as the change in ordering pattern was very little.

		Holding £	Backlog £	Ordering £	Total £	Fill Rate %
No Breach	Retailer	0.04	140.04	54.83	**194.90**	0.42
	Wholesaler	1.93	55.97	54.80	**112.69**	0.64
	Manufacturer	24.69	5.09	59.62	**89.40**	0.95
	Total	**26.66**	**201.10**	**169.24**	**396.99**	
BREACH IMPACT (Percentage change in cost)						
		Holding	Backlog	Ordering	Total	Fill Rate %
SFDD	Retailer	-18311	17	1	**9**	5
	Wholesaler	-595	18	0	**-1**	4
	Manufacturer	-39	-226	1	**-23**	-9
	Total	**-105**	**11**	**1**	**-1**	
AOW	Retailer	-9705	34	2	**23**	10
	Wholesaler	-520	49	2	**16**	14
	Manufacturer	-21	65	3	**0**	3
	Total	**-71**	**39**	**2**	**16**	
IBMS	Retailer	-217	5	0	**4**	1
	Wholesaler	-27	7	0	**3**	2
	Manufacturer	-2	-3	0	**-1**	0
	Total	**-4**	**6**	**0**	**3**	
PT	Retailer	-311	7	0	**5**	2
	Wholesaler	-42	11	0	**5**	3
	Manufacturer	-3	-3	0	**-1**	0
	Total	**-6**	**8**	**0**	**4**	

Table 5.4 Cost impact of security breach on option I ordering policy (negative indicates increase while positive indicate a decrease)

The result in Table 5.4 also suggests a breach increases the daily supply chain holding cost and a proportional decrease in supply chain daily backlog cost, although this might be different for the respective supply chain agents. The reason for this observation stems from our assumption in the model that during a breach, the retailer does not receive any demand information and consequently fulfils only the outstanding backlogs during this period. This breach period creates a somewhat 'pseudo-respite period' for the retailer and wholesaler where all the outstanding backlog can be fulfilled and any excess inventory received from the upstream agent during this time is stored, hence the increase in holding cost. After the disruption period the demand information accumulated during this period suddenly becomes available and the flexibility of the base stock policy ensures that the supply chain is able to recover from the increased demand shock by placing orders which reflect the current state of the operation. The percentage increase in holding cost however is

highest at the retailer and lowest at the manufacturer for all the security breach examined, which indicates that the breach reverberating effect on holding cost reduces as one goes up the chain

Looking at the performance at the operational level of individual agents we see this impact varies depending on the profile of the breach, that is, the rate of occurrence (RoC) and the disruption duration. The effect of RoC on all supply agents is quite similar as their daily average operating cost performances improved with increased RoC with the manufacturer not faring as well as the other two agents. The only difference in the observation for the manufacturer compared to those of the retailer and the wholesaler is that BP1 had a negative impact on the backlog cost of the manufacturer whereas the impact was positive on the retailer and wholesaler's backlog. This observation at the manufacturer is due to the assumption that the manufacturer has a production lead time of 3 days and transportation lead time of 2 days which means it takes the manufacturer a total of 5 days to get the product to the wholesaler. Therefore there is no 'pseudo-respite time' for the manufacturer to fill outstanding backlogs. Under BP2 (AOW) however, the manufacturer experienced a positive effect in its backlog. This is because BP2 (AOW), being a highly frequently occurring breach, creates a sort of learning curve effect where its repetitive nature causes the order quantity at each ordering point to be larger than its less repetitive counterpart (IBMS and PT) thus making the manufacturer carry more inventory. This increases the fill rate ability of the manufacturer and hence improves its backlog performance than any other breach type. However the balance between the improved backlog and increased holding cost does not yield a positive benefit, hence zero effect of BP2.

Examining the influence of disruption duration, it is obvious that significantly increasing the disruption duration improves the daily average operating cost performance of the retailer but this improvement is not as large as the effect of RoC. However, the effect of disruption duration on the performance of the wholesaler and manufacturer is a worsening effect. The effect of the longer disruption period in BP3 results in higher holding cost as inventory is held for longer period while the pipeline inventory satisfies the pre-existing backlog. This causes an improvement in the backlog cost of the retailer and the wholesaler but the increase in holding cost outweighs the decrease in backlog cost for the wholesaler. The manufacturer's

backlog is worsened than under BP3. The obvious reason for this is that the manufacturer does not enjoy the pseudo-respite period that the retailer and the wholesaler enjoys. Since the disruption period in BP1 (IBMS) is only one day, the effect on backlog cost is only a 3% increase. However, the disruption period in SFDD is 5 days creating a bigger effect on backlog cost increase (at 226%).

However the impact on the total supply chain daily operating cost is either positive or negative depending on the profile of the breach under the base stock policy. BP1 and BP2 both have an oddly positive effect on the total supply chain daily operating cost with BP2 having the highest positive benefit. Consequently the effect of RoC is an increase in positive benefit to the supply chain. On the other hand, BP3 had a negative effect, therefore comparing BP1 to BP3 suggest that the effect of disruption duration is a worsening of supply chain daily average operating cost performance as shown in Table 5.4.

The general observation under the parameter based ordering policy such as the base stock policy is that the reverberating effect of BP1, BP2 and BP3 increases as one goes upstream the chain, although BP1 and BP2 have an oddly positive effect on retailer and wholesaler's performance. It is also clear that increasing RoC of a breach produces a resultant positive effect on supply chain daily total operating cost while disruption duration produces a resultant negative effect.

5.2.2.2 Batch ordering policy (option II)

Although being an optimal EOQ model under normal circumstances, the order quantity produced under option II is somewhat the same and does not change significantly to cope with the effect of the breach. This means that the effect of the pseudo-respite period would be negated by the inability of the policy to increase order quantity to satisfy the relatively large demand coming in after the disruption duration. Therefore, in contrast to option I where the pseudo-respite period effect led to a reduction in backlog cost, the inflexibility or lack of resilience of option II would result in a backlog cost rise. The impact of each security breach on supply chain using option II ordering policy is shown in Table 5.5. The performance under a non-breach scenario and the percentage rise or fall in cost performance and fill rate performance under each security breach is shown.

		Holding £	Backlog £	Ordering £	Total £	Fill Rate %
No Breach	Retailer	2.41	63.35	54.25	**120.00**	0.61
	Wholesaler	16.98	16.90	52.93	**86.81**	0.86
	Manufacturer	39.21	9.07	54.68	**102.96**	0.92
	Total	**58.60**	**89.32**	**161.85**	**309.77**	
BREACH IMPACT(Percentage change in cost)						
		Holding	Backlog	Ordering	Total	Fill Rate %
SFDD	Retailer	-327	-225	0	**-125**	-29
	Wholesaler	-27	-100	0	**-25**	-11
	Manufacturer	-4	-35	0	**-4**	-3
	Total	**-24**	**-182**	**0**	**-57**	
AOW	Retailer	-29	-41	0	**-22**	-8
	Wholesaler	-3	-9	0	**-2**	-1
	Manufacturer	0	3	0	**0**	0
	Total	**-2**	**-30**	**0**	**-9**	
IBMS	Retailer	-15	-5	0	**-3**	-1
	Wholesaler	-1	-4	0	**-1**	-1
	Manufacturer	0	-2	0	**0**	0
	Total	**-1**	**-5**	**0**	**-2**	
PT	Retailer	-18	-10	0	**-6**	-2
	Wholesaler	-2	-7	0	**-2**	-1
	Manufacturer	0	-2	0	**0**	0
	Total	**-1**	**-8**	**0**	**-3**	

Table 5.5 Cost impact of security breach on Option II ordering policy (negative indicates increase while positive indicate a decrease)

Suffice to say that the ordering cost is expected to stay the same if no changes occur to the rate and quantity of the orders. Considering that there was no change in ordering pattern, the daily average ordering cost of all supply chain agents was not impacted by any of the security breaches. The impact of all the security breaches, however, was a rise in total supply chain holding cost and backlog cost. The level of impact again differs for each supply chain agent depending on the profile of the breach. Also, the reverberating effect tends to decrease as one goes further upstream.

Again, to examine the effect of RoC on individual performance, it is evident that that increasing the RoC of the breach worsens the performance of the retailer but has no apparent effect on the performance of the wholesaler and manufacturer. On the other hand, increasing the disruption duration worsens the performance of all supply agents with the retailer worse off and the manufacturer least affected. However,

examining the effect of the breach profile on supply chain performance, it is clear that disruption duration has a very large effect on supply chain performance than RoC with both producing a negative effect.

In conclusion, the breach reverberating effect diminishes under BP1, BP2 and BP3 as one goes upstream the chain. Increasing the RoC only negatively affects the performance of the retailer and this effect produces a resultant negative effect on the entire supply chain performance while increasing the disruption duration of the breach increases the negative impact a breach has on the supply chain and all its members.

5.2.2.3 Combined batch-and-parameter based policy (option III)

The impact of each security breach on supply chain using option III ordering policy is shown in Table 5.6. Like option I, BP2 and BP3 caused a very significant reduction in the ordering rate of option III which led to a significant reduction in the daily average ordering cost of supply agents. On the other hand, the reduction of the ordering rate due to BP1 is not large enough to offset a change in daily average ordering cost of the supply chain under the combined batch-and-parameter based ordering policy (III). Considering the impact of these breaches on other cost performance measures (as shown in Table 5.6), the holding cost of all supply agents was increased, as expected, but the effect on backlog differed based on the breach profile.

In general the combined batch-and-parameter based ordering policy behaves like the parameter based policy under information security breach but retains the optimality that the additional EOQ component provides. Therefore the impact of a security breach on its performance is generally in between the performance of parameter based and batch ordering policies under the same breach.

The main observation here (Table 5.6) is that increasing the RoC negatively affects the performance of all the supply agents, although the effect is not very large. An increase in the disruption duration on the other hand negatively affects supply agents' performances and this effect is greater than the effect of RoC. Interestingly, the reverberating effect of a breach of the type BP1 increases only slightly, as one goes up the chain while BP2 and BP3 increases and then decreases after the wholesaler tier.

		Holding £	Backlog £	Ordering £	Total £	Fill Rate %
No Breach	Retailer	1.94	50.01	54.73	**106.68**	0.67
	Wholesaler	12.90	12.56	54.26	**79.72**	0.89
	Manufacturer	56.60	0.60	56.30	**113.50**	0.99
	Total	**71.44**	**63.17**	**165.28**	**299.90**	
BREACH IMPACT(Fractional change in cost)						
		Holding	Backlog	Ordering	Total	Fill Rate
SFDD	Retailer	-621	-12	1	**-17**	-3
	Wholesaler	-129	-78	0	**-33**	-7
	Manufacturer	-13	-1475	1	**-14**	-8
	Total	**-51**	**-39**	**1**	**-20**	
AOW	Retailer	-553	21	2	**1**	5
	Wholesaler	-116	33	1	**-13**	3
	Manufacturer	-10	68	2	**-4**	0
	Total	**-44**	**24**	**2**	**-5**	
IBMS	Retailer	-37	7	0	**3**	2
	Wholesaler	-9	8	0	**0**	1
	Manufacturer	-1	-15	0	**0**	0
	Total	**-3**	**7**	**0**	**1**	
PT	Retailer	-50	8	0	**3**	2
	Wholesaler	-14	11	0	**0**	1
	Manufacturer	-1	-16	0	**-1**	0
	Total	**-5**	**9**	**0**	**1**	

Table 5.6 Cost impact of security breach on option III ordering policy (negative indicates increase while positive indicate a decrease)

5.2.3 Summary of Findings and Discussion

This study has shown that priorities as to which element of the breach profile (disruption duration or RoC) should be addressed depends on the ordering policy of choice. This would also inform which aspect of risk management measures to prioritise. For a parameter based ordering policy, increased RoC only increases the positive effect of a breach on the performance of the parameter based ordering policy while disruption duration increases the negative effect. Therefore supply chain priority for such parameter based ordering policy would be to focus on reducing the disruption duration of a breach, hence breach correction or mitigation would be a priority. The priority for a supply chain with batch ordering policy and that for a combined batch-and-parameter based ordering is also breach mitigation as disruption duration had a greater effect on breach cost impact than RoC.

The breach cost impact reverberating effect differs for the three ordering options considered. The effect consistently increases for all three breach profiles considered under the parameter based policy while the effect consistently decreases under the batch ordering policy. Under the combined policy however, the reverberating effect increases slightly when faced with breach of type BP1 and the effect increases and then decreases at the manufacturer. Therefore supply chains using the parameter based ordering would be more wary of information security breach occurring downstream in the supply chain than those using batch ordering policy. In a supply chain using the combined policy type, the wholesalers should be particularly wary of information security breach occurring downstream. In all, members of the supply chain existing in the upstream part of the supply chain would be affected by information security breach occurring at the downstream side of the chain due to the reverberating effect of the breach. This study therefore calls for better cooperation among supply partners and supports the claim that information security breach incidence and data should be shared between supply chain partners. This would help the non-breached, but affected, partners better prepare for eliminating or reducing the reverberating effect of such breach.

Finally, recall from the previous chapter that under normal circumstances (i.e. no security breach), the batch ordering policy performs better than the parameter based ordering policy. However in this chapter, the result has shown that the parameter based policy outperforms the batch ordering policy when breach RoC is high (BP2) or disruption duration is high (BP3). However when the breach is of the type BP1, the batch ordering policy still outperforms the parameter based ordering policy. The combined batch-and-parameter based policy performs best in both breach and non-breach situations. So far the performance of each ordering policy under information security breach has been assessed in a serial non-information sharing scenario (i.e. the base model). The next section evaluates the effect supply chain structural reconfiguration strategy has on the impact of information security breach. The question here is; can structural reconfiguration be used as a cost mitigation strategy even under disruption situations caused by information security breach?

5.3 STRUCTURE EFFECT ON BREACH IMPACT

To estimate the mitigating effect of supply chain structure on the impact of security breach, the difference between the impact of security breach on the base model and that of the reconfigured scenario relative to the base model is computed. First the impact of security breach on the base model is calculated and expressed as a percentage (as explained in section 5.2). Then the impact of security breach on the reconfigured scenario relative to the base model is computed (also expressed in percentage). The difference between these two percentages is an estimation of how much reduction in breach impact can be derived when structural reconfiguration is adopted. This method of computation is used because it ensures that all the breach impacts computed have a common relative point (the base model with no breach) which makes the impact mitigation percentage comparison between structures more direct and accurate. This percentage difference is termed 'structure effect on breach impact' (SEOBI) and is tested for significance at $p<0.05$ to show whether the effect of SEOBI is statistically significant at $p<0.05$ or not. If the SEOBI is not significant at $p<0.05$, then SEOBI is said to be non-existent. Otherwise the effect is said to be existent. The direction of the effect on operating cost can be of a positive type (mitigating), a negative type (exacerbating) or neither (stabilising). A negative value reveals an exacerbating effect while a positive value indicates a mitigating effect. A non-significant value shows that the structure effect is of a stabilising nature regardless of it being either positive or negative. The SEOBI on each supply agent for each of its performance measures (daily average holding, backlog, ordering costs) and that on the entire supply chain is computed for each ordering policy. However all the tables shown in this section only include the effect on total daily average operating cost of each agent (R- retailer, W- wholesaler, M- manufacturer) and not the individual daily average costs. The values with superscript 'nd' indicate that the percentage difference is not statistically significant at $p<0.05$.

5.3.1 WH Structure Effect on Breach Impact

The result shown in the Table 5.7 is the percentage change between the performance of a serial chain under security breach and that of a wholesaler structure type under security breach.

	SFDD			
	R. Cost %	W. Cost %	M. Cost %	SC Total %
option I	-4	6	19	4
option II	60	21	10	32
option III	10	30	13	16
	AOW			
	R. Cost %	W. Cost %	M. Cost %	SC Total %
option I	-10	-2nd	5	-5
option II	8	9	7	8
option III	-4	13	4	4
	PT			
	R. Cost %	W. Cost %	M. Cost %	SC Total %
option I	-5	-2nd	6	-2nd
option II	0nd	9	7	5
option III	-1nd	11	4	4
	IBMS			
	R. Cost %	W. Cost %	M. Cost %	SC Total %
option I	-4	-1nd	6	-1nd
option II	-1nd	9	7	4
option III	0nd	11	4	4

nd- means no significant difference at $p<0.05$

Table 5.7 Percentage change in impact due to wholesaling simplification

5.3.1.1 Influence of WH under Option I Scenario

As revealed in Table 5.7, the WH structure has a mitigating effect under option I when a very disruptive security breach (BP3) is encountered with a 4% reduction in SFDD breach impact. However, WH effect makes the impact of a less disruptive but highly recurring breach (BP2) on supply chain performance worse than it would be in a serial supply chain i.e. exacerbating effect. The exacerbating effect under the less disruptive and less recurring breaches PT and IBMS (BP1) is not significant, hence considered to be a stabilising effect. Therefore WH structure has a stabilising effect on less disruptive, less recurring breaches but when the RoC is at higher levels an exacerbating effect is seen.

At the operational level, the WH structure has an exacerbating impact on the retailer's total operating cost performance under highly disruptive and less disruptive breaches. However, the WH-exacerbating effect is not increased with increasing disruption duration but increasing the RoC does. For the wholesaler, WH structure has a mitigating effect under a highly disruptive breach and a stabilising effect under a less disruptive breach. The stabilising effect is not affected by increasing the RoC of the breach. The impact of both highly disruptive and less disruptive (but highly

occurring) breaches on the manufacturer's total operating cost performance is mitigated under WH structure. This mitigation effect is seen to increase as the disruption period increased (between IBMs and SFDD). RoC however does not seem to have any impact on the mitigating effect of WH structure on manufacturer's total operating cost performance.

5.3.1.2 Influence of WH under Option II Scenario

At the supply chain level, the WH structure appears to hold significant benefit over the serial structure both in no-security breach and security breach scenarios. Under all the security breach scenarios considered, a WH-mitigating effect is observed as shown in Table 5.7. The mitigating effect is highest under a more disruptive breach (SFDD) than a less disruptive one (IBMS). Comparing the mitigating effect under AOW (8%), PT (5%) and IBMS (4%) reveal that increasing the RoC increases the mitigation WH structure stand to offer.

At the operational level, the retailer enjoys a mitigation of the impact of a very disruptive breach on its daily operating cost performance under WH structure. For less disruptive breaches such as IBMS and PT, an exacerbating effect is felt at the retailer's end, however not significant (stabilising effect). The exacerbating effect, although insignificant, is seen to reduce as RoC increases. However, this changes to a mitigating effect when RoC is significantly increased as in the case of AOW breach (at approximately 8% mitigation). The wholesaler and the manufacturer on the other hand enjoys a mitigation effect regardless of the breach type. They both enjoy higher mitigation levels under a more disruptive breach (SFDD) than less disruptive ones. The mitigation level is however not significantly affected by RoC increase.

5.3.1.3 Influence of WH under Option III Scenario

The WH structure is also favourable towards ordering policy of the type 'option III' in the event of the security breaches mentioned. As shown in Table 5.7, regardless of the nature of the breach, the WH structure has a mitigating effect on the magnitude of the impact of highly disruptive and less disruptive breaches. Higher levels of mitigation occur when the breach is highly disruptive than when the breach is less disruptive. A higher level of RoC does not seem to congruently affect the mitigation

level, although this appear to reduce with increasing RoC. However the rate of change of the mitigation level does not correspond with the rate of change of RoC.

At the operational level of the supply chain, mitigating effect is only seen to occur under a highly disruptive breach (10%) at the retailer's end while the effect to the retailer's daily operating cost is of an exacerbating nature under a less disruptive breach. Although the exacerbating level under PT and IBMS is insignificant at $p<0.05$, the level is however significant under a breach with much higher RoC (AOW). Therefore for a less disruptive breach, the exacerbating effect is insignificant at lower RoC but become significant with significantly higher RoC. On the hand, the wholesaler and the manufacturer both enjoy a WH-mitigation of security breach impact on their respective daily operating cost performance. While they both enjoy increased mitigation under a highly disruptive breach (comparing SFDD to IBMS), the mitigation level enjoyed by both agents is unaffected by increased RoC. Therefore, for the wholesaler and manufacturer, RoC has no effect on the magnitude of mitigation derivable from a WH structure.

5.3.1.4 Summary and Implication of Finding

This section has established that reconfiguring the supply chain from the serial structure to the WH configuration can provide benefit both in a security breach scenario and in a non-security breach scenario. This benefit of course depends on the ordering policy of choice and the profile of the breach.

Under option I scenario, WH effect is inconsequential when a breach of the type BP1 occurs but becomes disadvantageous when the breach in question has a high recurrence rate. However, it provides a mitigation benefit when the disruption duration of the breach is high. Therefore the implication of this to the IT manager is that when WH structure is adopted, then more focus is needed in breach prevention and deterrence rather than breach mitigation measures.

For option II and III, WH effect provides mitigation benefits to the supply chain. Even in the event of that the disruption duration or recurrence rate of the breach increases significantly, WH structure provides increased mitigation benefit. Therefore the cost benefit from reconfiguration can be used to upgrade or augment existing risk prevention and mitigation tools that were previously unaffordable. This

in turn would help prevent future attack from occurring or mitigate it better when it occurs and further cost savings can be derived.

5.3.2 MF Structure Effect on Breach Impact

The values presented in in Tables 5.8 represent the percentage increase (if negative) or decrease (if positive) in impact cost due to the Manufacturing Structure (MF) effect.

	SFDD			
	R. Cost %	W. Cost %	M. Cost %	SC Total %
option I	-4	2nd	25	4
option II	60	13	15	32
option III	8	18	16	14
	AOW			
	R. Cost %	W. Cost %	M. Cost %	SC Total %
option I	-12	-8	11	-6
option II	8	1nd	13	8
option III	-1nd	6	9	5
	PT			
	R. Cost %	W. Cost %	M. Cost %	SC Total %
option I	-3nd	-2nd	11	1nd
option II	0nd	0nd	13	4
option III	-3	0nd	6	2
	IBMS			
	R. Cost %	W. Cost %	M. Cost %	SC Total %
option I	-2nd	-1nd	11	1nd
option II	-1nd	0nd	13	4
option III	-2nd	0nd	6	2

nd- means no significant difference at $p<0.05$

Table 5.8 Percentage change in impact due to manufacturing simplification

5.3.2.1 Influence of MF under Option I Scenario

Considering the profile of a security breach in terms of the disruption duration and the frequency with which the breach occurs (also known as RoC), the mitigating role of MF structure is more favourable towards the disruption duration than RoC. In fact as Table 5.8 suggest, MF effect responds negatively to increasing RoC. From the result it is apparent that under high RoC, the stabilising effect of MF diminishes and an exacerbating effect is seen. Based on disruption duration, MF structure tend to have a mitigating influence on the impact a highly disruptive breach has on supply chain daily operating cost. The stabilising effect of MF structure under BP1 improves and becomes a mitigating type under BP3, confirming that MF effect is more favourable towards a breach with higher disruption duration.

Looking at the performance of individual supply chain agents under security breach, the retailer is not favoured under the MF structure effect. The performance of the retailer is worsened under the MF structure revealing that MF has an exacerbating effect on how security breach impacts the retailer. In fact this performance is made worse under higher levels of disruption duration and RoC. Interestingly for the wholesaler, a statistical test shows MF structure has a stabilising effect on the impact of a highly disruptive breach. In other words increasing the disruption duration has no impact on the stabilising effect of the MF structure on wholesaler daily operating cost performance. RoC however has an impact on the stabilising effect of MF. The MF effect on the performance of the wholesaler under a breach of type BP1 is of a stabilising nature, however this stabilising effect diminishes as RoC increases significantly resulting in an exacerbating effect. The manufacturer on the other hands benefits from the MF effect especially under a more highly disruptive breach. The MF structure has a mitigating effect on the impact of security breach on manufacturer's daily operating cost. The level of mitigation is unaffected by varying levels of RoC but is increased under higher disruption duration.

5.3.2.2 Influence of MF under Option II Scenario

At the strategic level (that is the supply chain level), a mitigation of the impact of security breach on supply chain cost performance is observed regardless of the security breach profile as shown in Table 5.8. The more disruptive the breach the better the mitigation effect derivable and the higher the RoC the higher the mitigation level.

At the operational level (that is the individual supply chain agent level), the retailer either experiences a stabilising effect or a mitigation effect depending on the profile of the breach. For a less disruptive breach such as PT and IBMS, the retailer experiences a stabilising effect. However this stabilising effect transmogrify into a mitigating type when the RoC is significantly increased as in AOW (8%). For the more disruptive breach type (SFDD) a mitigation effect is observed at the retailer's end. The MF effect changes from a stabilising nature to a mitigation type when the disruption duration of the breach increases significantly as revealed by the comparison between the influences on IBMS (stabilisation at 1%) and SFDD (mitigation at 60%). The influence on the wholesaler breach performance again depends on the profile of the breach. This influence is positive for a more disruptive

breach and neutral for a less disruptive type. Therefore, regardless of the RoC level of the less disruptive breaches, MF consistently had a stabilising effect on the impact of this breach type on wholesaler daily operating cost performance. However, this influence goes from a stabilising 0% under IBMS (a less disruptive breach) to a mitigating 13% under SFDD (a more disruptive breach). This again shows that the wholesaler enjoys greater mitigation influence when the disruption duration is increased and maintains a stabilising effect even if the RoC is increased significantly.

The manufacturer enjoys a mitigation of the impact of security breach under the MF structure. The mitigating influence of MF on the impact of security breach on the manufacturer's daily operating cost is not significantly perturbed by increasing RoC and increasing disruption duration. As shown by the result the mitigation level remains at the same level for AOW, PT and IBMS, while there is only a slight increase in mitigation level between IBMS and SFDD and this slight increase is not commensurate with the increase in disruption duration.

5.3.2.3 Influence of MF under Option III Scenario

The supply chain enjoys an improved cost performance in the event of a security breach when the MF structure is preferred over the serial structure type as shown in Table 5.8. Regardless of the breach profile, a mitigation effect is observed on supply chain performance; meaning the worse the breach gets, the better is the derived benefit. Worsening the breach by increasing the RoC or the disruption duration further increases the benefit derived from MF structure. Although a slight increase in RoC (comparing IBMS and PT) does not change the level of mitigation, however, a significant increase in RoC level produces a reasonable increase in mitigation effect.

There is no tangible effect of MF structure on the impact of less disruptive breaches on the retailer's daily operating cost performance, however for more disruptive breaches the effect is tangible. Increasing disruption duration means the MF structure is able to provided added benefit to the retailer with structure influence going from stable under BP1 to higher mitigation under BP2. Increasing RoC has no consistent effect on the influence MF has on retailer's cost impact. There is tangibility in the effect disruption duration and RoC has on the way MF influences the wholesaler's cost impact. Increasing breach RoC slightly does not change the level of influence

MF has on wholesaler's performance, however, a significantly elevated RoC produces a marked improvement in MF mitigation effect. Again, the wholesaler in the MF structure reacts much better than one in the serial counterpart to increased disruption duration of information security breach. For the manufacturer however, a step change in RoC only slightly improves the mitigation effect of MF structure. Increased disruption duration from one day to five days changes the level of mitigation on manufacturer's cost impact from 6% to 16%.

5.3.2.4 Summary and Implication of Finding

Like the WH structure, the MF structure also influences the way the supply chain reacts to demand and also to information security breach. The result has further strengthened the argument that 'susceptibility' of an ordering policy to structural change determine how much breach impact mitigation the supply chain is able to enjoy when such structural changes are made. Under the manufacturing structure, option I was the least susceptible to structural and option II was the most susceptible while option III was median susceptible in a non-breach scenario. The result from this section has shown that the mitigation level of MF configuration towards option II performance is highest followed by option III with option I deriving the least benefit, confirming the argument.

It has also been established that reconfiguration from a serial structure into a manufacturing structure holds benefit to the supply chain in a non-breach and breach scenarios. In the breached scenario, the level of benefit depends on the ordering policy and the breach profile.

Under option I, changing to a MF structure ensure that the supply chain would enjoy a reduction in impact cost when a more disruptive breach occurs although the MF structure has no significant effect when the breach in question is of a less disruptive type. However, under option I, the MF structure is not able to provided benefit to the supply chain and in fact exacerbates the impact cost when the breach recurrence rate is significantly high. This therefore implies that upon changing to this structure type, the prevention and deterrence measure would require more focus than they would in a serial chain.

For option II and III, MF structure brings about a mitigation of breach cost impact for the supply chain. Therefore, cost benefit of MF structure under security breach

exists regardless of the breach profile whether disruption duration or RoC is high or low. The implication of this therefore is that the impact cost benefit derived can be redirected towards improving IT security which will yield added benefits on the long run.

5.3.3 Network Structure Effect on Breach Impact

This section evaluates how the magnitude of security breach impact is changed by network reconfiguration under the three ordering options. The network effect (NT-effect) on breach impact is shown in Table 5.9.

		SFDD		
	R. Cost %	W. Cost %	M. Cost %	SC Total %
option I	-4	4	19	3
option II	58	16	15	32
option III	9	27	13	15
		AOW		
	R. Cost %	W. Cost %	M. Cost %	SC Total %
option I	-10	-4	5	-5
option II	7	6	12	9
option III	-4	11	5	3
		PT		
	R. Cost %	W. Cost %	M. Cost %	SC Total %
option I	-5	-4	6	-2
option II	-1^{nd}	6	13	5
option III	-1^{nd}	7	4	3
		IBMS		
	R. Cost %	W. Cost %	M. Cost %	SC Total %
option I	-4	-4^{nd}	5	-2^{nd}
option II	-2^{nd}	5	13	5
option III	-1^{nd}	7	5	3

nd- means no significant difference at $p<0.05$

Table 5.9 Percentage change in impact due to network configuration

5.3.3.1 Influence of Network Structure under Option I Scenario

Under the network structure, the impact of the security breach on supply chain cost performance is only alleviated when the breach has a higher level of disruption duration as shown in Table 5.9. This is seen in SFDD where the influence of NT-structure is a mitigation type at 3% compared to IBMS which is of a stabilising nature at -2%. However, the influence becomes an exacerbating type when the RoC of the breach increases as evidenced by the result of AOW, PT and IBMS.

A similar trend is observed for the wholesaler where N-effect causes a mitigation of the impact a highly disruptive breach (SFDD, 4%) has on wholesaler's daily operating cost performance. The effect on the less disruptive breach type (IBMS, -4%) is not significant but is significant under high RoC (AOW, -4%). Therefore, under this structure, the wholesaler should be more wary of increase in RoC rather than disruption duration. The retailer does not benefit from the N-effect and in fact the N-effect makes impact worse when disruption duration and RoC are increased as the result suggest. The manufacturer on the other hand enjoys a mitigation benefit from the N-structure configuration. The benefit to the manufacturer's daily operating cost performance increases under increased disruption duration but this benefit appears unperturbed by increasing RoC.

5.3.3.2 Influence of Network Structure under Option II Scenario

At the supply chain level, the effect of reconfiguration from a serial structure to a network structure brings benefit to the way the supply chain is impacted by security breach. The impact of information security breach on a supply chain with network type configuration would fare better than one with serial configuration. This observation is evidenced from the result in Table 5.9 where the percentage change in impact from serial to network structure is positive for all the security breach types. That is, NT-effect on supply chain cost performance is of a mitigation nature rather than stabilisation or exacerbation nature. It is also clear that the level of mitigation is in turn influenced by the profile of the breach in terms of disruption duration and rate of occurrence (RoC). The mitigating effect of NT-structure in seen to increase significantly under a breach with higher disruption duration when the result for IBMS (5%) is compared to that of SFDD (32%). In the same light the mitigating effect also increase under increased RoC when IBMS (5%), PT (5%) and AOW (9%) are compared.

At the operational level in the supply chain, the benefit to the retailer only comes when the breach is more disruptive and highly prevalent. N-effect has a stabilising influence on the way the retailer's daily operating cost is impacted by less disruptive and less frequently occurring breaches in a serial supply chain. However when the breach is more disruptive or recurring, the benefit to the retailer is increased and a good mitigation level is seen especially when the breach is more disruptive. The story is somewhat different for the wholesaler. Although the wholesaler enjoys a

mitigation of the security breach impact cost, this mitigation level only significantly increased under increased disruption duration but not RoC. Therefore, there is no increased N-effect benefit to the wholesaler under increased breach RoC, or at least the step increase in RoC is not commensurate with the increase in benefit. A similar observation to that of the wholesaler is found at the manufacturer's end. Although there is an observed mitigation effect on manufacturer's daily operating cost performance, the level of mitigation is not commensurate to the level of increase in disruption and RoC levels. Therefore there is no apparent increase in benefit to the manufacturer if the profile elements of the breach (that is disruption duration and RoC) is raised.

5.3.3.3 Influence of Network Structure under Option III Scenario

The influence of the network structure on option III is also shown in Table 5.9. A mitigating effect is observed at the supply chain level for all breach types. This mitigation level is increased between IBMS (3%) and SFDD (15%). Confirming that an increased disruption duration does not worsen the role N-effect plays in mitigating breach cost impact, but in fact reveals that N-effect has higher counteracting effect. The result also shows that the mitigation level is not significantly changed between IBMS (3%), PT (3%) and AOW (3%). Confirming that the counteracting effect of N structure is not affected by increased RoC.

For the retailer, the N-effect stabilises the impact of a less disruptive breach type on its daily operating cost performance. However this stabilisation diminishes when the RoC of the breach increases and an exacerbating effect is observed. For a more disruptive breach, the observed stabilising effect of the network structure is strengthened and the breach impact is further absorbed by the structure creating a mitigating effect. The wholesaler and the manufacturer both enjoy a mitigation of the impact of security breach on their daily operating cost performance. Both agents also enjoy an increase in the mitigation level in the event of increased disruption duration. However the benefit to the manufacturer appear to be unaffected by increased RoC while that to the wholesaler is. The wholesaler enjoys better performance under a breach with significantly high RoC as shown by the AOW result.

5.3.3.4 Summary and Implication of Finding

This section further validate the argument that supply structure play a mitigation role on the way security breach impact the supply chain.

Under ordering option I, the network structure has an exacerbating effect on supply chain performance when faced with a less disruptive breach and this negative effect increases when RoC increases. This effect however diminishes and becomes a mitigating effect when the breach becomes more disruptive. The implication of this is that upon transformation into the network structure, more attention need to be paid to improving the breach prevention and deterrence strategy than breach correction strategy.

With option II, the N-effect result in a mitigation of security breach impact on supply chain performance and the level of mitigation increases when faced with more highly disruptive or recurring breach. Consequently, the IT manager need not worry about raising IT security effort because of structural change. In fact reconfiguring the chain into a network type structure generates benefits that can be redirected into fortifying IT security.

For option III, the network structure improves the response of the supply chain to breach impact by mitigating the cost impact. The level of mitigation increases when the disruption duration of the breach significantly increases but the remains at the same level when RoC significantly increase instead. This implies that the mitigated cost can be re-invested into improving the security level.

5.3.4 Summary of Findings and Discussion

The decision framework of whether to accept the improvement strategy as breach cost impact mitigation strategy for each supply agent is shown in Figure 5.2.

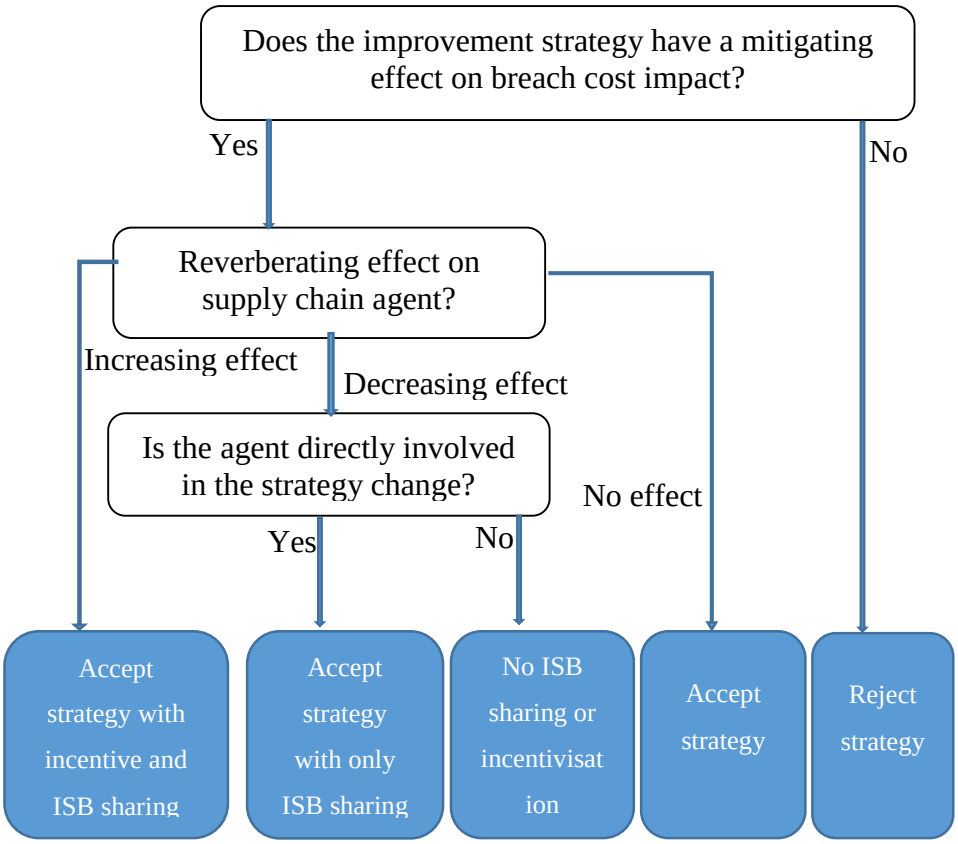


Figure 5.2 Single strategy acceptance decision framework in a breach scenario

First the cumulative effect of structural reconfiguration on breach impact for each scenario is computed and if this computation is positive then the strategy has a mitigating effect and is therefore acceptable, otherwise it is not acceptable. The reverberating effect is understood by computing the cumulative effect of the improvement strategy for each supply agent and then examining if this increases or decreases along the supply chain. If the reverberating effect decreases but is still significant upstream, then perhaps the retailer should immediately notify the upstream partners of any breach so they can quickly respond to the effect such breach might have. This is known as information security breach (ISB) sharing. If, on the other hand, the reverberating effect of the breach increases or if the impact experienced at the retailer is less than that experienced upstream, then the affected party should be provided with some form of breach impact incentive in addition to the incentive that ought to be provided under normal circumstances considering the type of improvement strategy. This should also be done in addition to timely sharing of security breach information. However if the impact upstream is not significant then no incentivisation or ISB sharing from the retailer is required. Therefore reverberating effect has implication to ISB and incentivisation decision within the

supply chain. On the other hand understanding the effect of high RoC and disruption duration is important to knowing where Information security management (ISM) priorities lie. If a change in disruption duration from low to high has a greater negative effect than that of RoC for any supply chain scenario, then IT priority would be on corrective measures (C), otherwise the priority would be prevention & deterrence (P&D).

The summary of the result is shown in Table 5.16. The decision to accept an improvement strategy is based on whether the aggregate benefit derived from the non-breach scenario (n-BS) and the breach scenario (BS) is positive or not and the implication to ISB sharing; additional breach impact incentivisation; and information security management (ISM) priority is also indicated. The general observations are listed below:

- Structural reconfiguration by itself does not mitigate the impact information security breach has on supply chain performance for a parameter based policy (option I) but instead makes it worse. The only exception is the MF structure where benefit is derivable and the retailer needs to share ISB information with the wholesaler.
- Reconfiguration will prove beneficial to batch ordering systems (option II) and batch-and parameter based policy (option III) in a security breach scenario but ISM focus should be on prevention and deterrence rather than corrective measures. In addition, there is no need for ISB sharing and incentivisation after a security breach.
- Similar to the non-breach scenario, the serial structure is again preferred under parameter based ordering policy while the networking strategy and the wholesaling simplification strategy are the best cost performers under batch and batch-and-parameter based policies respectively.
- ISM priority would be to focus more on prevention and deterrence when any of the structural reconfiguration strategies is adopted.

	Option I			Option II			Option III		
	WH	MF	NT	WH	MF	NT	WH	MF	NT
n-BS Benefit	0%	3%	0%	3%	3%	4%	5%	2%	4%
BS Benefit	-3%	1%	-6%	50%	48%	51%	29%	22%	25%
Total Benefit	-3%	4%	-6%	53%	51%	55%	34%	24%	29%
Acceptable?	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
ISB sharing with?	-	W	W	-	-	-	-	-	-
Incentive to?	-	-	-	-	-	-	-	-	-
IT priority	P&D	P&D	P&D	P&D	P&D	P&D	P&D	P&D	P&D

Table 5.10 Summary and implication of supply reconfiguration to information security breach impact

5.4 INFORMATION SHARING LEVEL EFFECT ON BREACH IMPACT

Information sharing level has been established in the previous chapter to provide benefit for certain supply chain members which can be shared with non-benefiting counterparts. The magnitude or direction of such benefit may be compromised by the incidence of information security breach. For all the benefits and performance improvement brought about by information sharing in a non-breach scenario, this study aims to determine whether this benefits are still applicable in a breach scenario and how the landscape of benefit changes. This study propose that based on the magnitude and direction of breach impact, the decision to engage in any level of information integration should not be taken until after breach impact considerations.

To estimate the benefit of information sharing, if any, in the face of security breach, the performance under an information sharing mode with breach is compared to that under a non-information sharing mode (NI-base model) with breach. The analyses here is similar to that in section 5.3, the only difference is that information sharing level (ISL) influence on breach impact is being considered instead of structure effect. Therefore the tables used in this section are derived in a similar fashion to those in section 5.3. Again, the influence of information sharing level on information security breach impact is examined to see if it is of a mitigating, exacerbating or stabilising

nature. A mitigating effect is such that the breach cost impact in a supply chain that has engaged in information sharing is significantly lower (at $p<0.05$) than that of the non-information sharing counterpart. An exacerbating effect is seen when the breach impact in the information sharing mode is significantly higher (at $p<0.05$) than that of the base model. A stabilising effect on the other hand occurs when there is no significant difference (at $p<0.05$) between the breach impact in both information sharing and non-information sharing scenarios. The values with superscript 'nd' indicate that the percentage difference is not statistically significant at $p<0.05$.

The pattern of analysis has been established throughout section 5.3. Therefore in this section the summary of the finding is given without going into details of how the analysis is done as this has been established already. Consequently, for each ISL, the MES effect is identified followed by the response of ISL to changing breach profile. In conclusion, the effect of increasing disruption duration and RoC is identified and the implication to information security management and supply chain inventory management is drawn.

5.4.1 Influence of RW on Breach Impact

The influence of having a RW level of information sharing when four main types of breach occurs is revealed in Table 5.11. Its effect on each supply agent and the total effect on supply chain operating cost for each ordering policy type is shown. Under the highly disruptive breach, RW mitigates the breach impact on an option I supply chain but the effect on the wholesaler and retailer is of the stabilising type while the manufacturer enjoys mitigation. In this case, RW mitigates the impact only at the upstream of the supply chain. Under a less disruptive breach however, RW mitigates the impact on supply chain operating cost with the retailer and wholesaler this time enjoying a mitigation while the manufacturer is unperturbed at $p<0.05$. Here RW has no significant influence on the impact of a less disruptive breach on the performance of the upstream part of the chain. The result in Table 5.11 suggest that RW is not very favourable to the supply chain when the breach is very disruptive (SFDD) but better mitigation is derived when the supply chain experiences a less disruptive kind. Examining the disruption duration effect and the RoC effect, the higher the disruption duration of a breach the lesser the derived benefit from RW configuration. The higher the RoC of a less disruptive breach, the lesser the derived benefit, although the margin is not very high. However the manufacturer appear to enjoy

more mitigation form RW when the RoC increases significantly. The implication of this finding is that although RW mitigates the impact of security breach on option I supply chain, more effort should be put in the breach mitigation than in the prevention measures.

	SFDD			
	R. Cost %	W. Cost %	M. Cost %	SC Total %
option I	0^{nd}	0^{nd}	8	2
option II	22	-8	-14	2^{nd}
option III	-8	-1^{nd}	10	1^{nd}
	AOW			
	R. Cost %	W. Cost %	M. Cost %	SC Total %
option I	6	2	12	6
option II	12	-6	-2^{nd}	2^{nd}
option III	4	0^{nd}	13	6
	PT			
	R. Cost %	W. Cost %	M. Cost %	SC Total %
option I	10	15	-1^{nd}	9
option II	7	4	-3^{nd}	3
option III	-3	-2	13	3
	IBMS			
	R. Cost %	W. Cost %	M. Cost %	SC Total %
option I	10	15	-2^{nd}	9
option II	6	4	-2^{nd}	3
option III	-3	-2	13	3

nd- means no significant difference at $p<0.05$

Table 5.11 Percentage change in impact due to RW ISL for all three ordering policy scenarios

Under option II scenario, the impact of the more disruptive and less recurring breach (SFDD) and the more recurring and less disruptive breach (AOW) on total supply chain performance were stabilised at $p<0.05$. Interestingly, the impact of the less disruptive and less recurring breaches (PT and IBMS) were mitigated with RW information sharing level. At the operational level, RW mitigates the impact of a highly disruptive breach on the retailer's average daily operating cost performance but the impact on the wholesaler and the manufacturer was in fact exacerbated. However, for the less disruptive breaches the retailer and wholesaler enjoys a mitigation while the manufacturer experiences a stabilising effect. When the RoC increases (as in the case of AOW), the obvious effect is on the wholesaler performance as it changes from mitigation to exacerbation. Overall, for breaches with high disruption duration and high RoC, RW does not provide any breach impact mitigation but it is only beneficial when the breach is less disruptive and has a low

recurring rate. Consequently the breach management effort need not be increased due to RW reconfiguration. However, any further efforts, if any, should be geared towards improving both prevention and mitigation measures.

For option III, RW stabilises the impact of a very disruptive breach on supply chain performance but mitigates the impact when the breach is less disruptive. When the less disruptive breach becomes more recurring the mitigation benefit of RW increases. At the operational level, the impact of a highly disruptive breach on the retailer, wholesaler and manufacturer is exacerbated, stabilised and mitigated respectively by RW. Under the less disruptive breach scenarios (PT and IBMS), the effect of RW is of the exacerbating type on the retailer and the wholesaler while the manufacturer enjoys a mitigation benefit. It is therefore apparent that the mitigation benefit enjoyed in a less disruptive breach scenario is as a result of the benefit to the manufacturer alone. However when the RoC of the breach increases significantly, the retailer appear to benefit from RW with a mitigation effect while the wholesaler enjoys a stabilising effect. Overall, the supply chain enjoys higher benefit under high RoC but reduced benefit under high disruption duration. Consequently for an option III supply chain, any efforts towards information security breach management under an RW ISL should prioritise mitigation over prevention.

5.4.2 Influence of WM on Breach Impact

The result of the MES effect of an integration between the wholesaler and the manufacturer only on individual and collective performance is shown in Table 5.12. For option I, the WM mode of integration appear to be beneficial only to the manufacturer depending on the breach profile. The mitigation of the less disruptive breach (IBMS) impact is about 13 % for the manufacturer while the effect is an exacerbation of the retailer and the wholesaler's cost performances. When the disruption duration is increased significantly, the effect of WM is slightly reduced for all supply chain agents. On the other hand, if the RoC is increased significantly, then the effect becomes a stabilisation on the retailer and the manufacturer's performance but that of the wholesaler is exacerbated further. Looking at the supply chain performance, it is seen that there is still a mitigation of breach impact by WM when the disruption duration of the breach increases. However the breach impact is

made worse when the RoC is very high. Consequently, engaging in WM ISL requires increased effort in breach prevention measures.

	SFDD			
	R. Cost %	W. Cost %	M. Cost %	SC Total %
option I	-2	-4	12	1
option II	-4	-5	7	0^{nd}
option III	-7	-7	22	4
	AOW			
	R. Cost %	W. Cost %	M. Cost %	SC Total %
option I	-2^{nd}	-7	0^{nd}	-3
option II	-2	-1	7	1
option III	0	-2	16	6
	PT			
	R. Cost %	W. Cost %	M. Cost %	SC Total %
option I	-2	-3	13	1
option II	-2	-1	8	2
option III	-6	-6	25	6
	IBMS			
	R. Cost %	W. Cost %	M. Cost %	SC Total %
option I	-2	-3	13	1
option II	-2	-1	8	2
option III	-6	-6	25	6

nd- means no significant difference at $p<0.05$

Table 5.12 Percentage change in impact due to WM ISL for all three ordering policy scenarios

In the option II scenario, under a less disruptive breach (IBMS), the mitigation effect of the WM mode on the total supply chain breach impact comes solely from the mitigation of the manufacturer's breach impact while the retailer and the wholesaler experienced an exacerbating effect. This effect is worsened for each supply chain agent when the breach becomes more disruptive but the overall effect to the supply chain performance is reduced from mitigation under the less disruptive kind to stabilisation under the more disruptive kind. However increasing the RoC instead has little effect on the level of influence WM has on the overall supply chain and the individual agents. To conclude, increasing disruption duration and RoC has little effect on supply chain breach impact. Therefore no added effort is required in information security management when the supply chain engages in WM mode. The breach mitigation measures should however be given priority if any effort is to be put into IT security management.

Under option III, it is evident that WM provides greater benefit to the manufacturer in the breach scenario than in options I and II scenarios. Examining the influence of

WM under a less disruptive and less recurring breach scenario, an exacerbating effect of the breach impact occurs at the retailer and the wholesaler while the manufacturer enjoys a mitigating effect. This of course results in the entire supply chain enjoying a mitigation benefit from WM ISL. However when the disruption duration is increased significantly, the retailer and the wholesaler still experience an exacerbating effect but this effect is slightly better than in the less disruptive breach scenario. The manufacturer still enjoys a mitigation benefit under an increased disruption duration but this benefit is less than the benefit in the less disruptive breach scenario. On the other hand, if the RoC alone is significantly increased, then the exacerbating effect in the less recurring scenario on both the retailer and the wholesaler is significantly reduced in the highly recurring scenario with the retailer now enjoying a small mitigation benefit and the wholesaler experiencing only a small exacerbating effect. The manufacturer experiences a reduction in the mitigation benefit provided by WM when the RoC increases significantly. However, the effect of increasing the RoC to levels similar to that of AOW does not change the WM effect on the overall supply chain breach impact, only on individual agents. In summary, WM offer mitigation benefits when a less disruptive and less recurring breach occurs and yet still offer mitigation benefits to breach impact when disruption duration and RoC are significantly increased. Consequently, for an option III supply chain, engaging in WM does not mandate an increased information security effort. However priority should be given to breach mitigation as WM produces a better mitigation when RoC increases than when disruption duration increases.

5.4.3 Influence of RWM on Breach Impact

The effect of having a full integration scenario, where all members of the chain are able to utilise the real time market demand data and other associated inventory information, on breach impact is shown in Table 5.13. From the table, it is evident that, under the base stock policy (option I), RWM effect on the impact of a less disruptive and less recurring information security breach (IBMS or PT) for all supply chain members is of the mitigation type. However this effect is lower, but still mitigating, when the breach becomes either highly disruptive or highly recurring for the retailer and the wholesaler. The manufacturer on the other hand experiences a stabilising effect instead when the disruption duration or the RoC increases significantly. Consequently under the RWM information sharing level, the impact of

a security breach is lesser here than in a non-information sharing mode under the same operating conditions, and the mitigation effect is higher when the breach is less disruptive and less recurring. Therefore moving from a non-integrated supply chain to a RWM integration level does not require any additional information security management efforts.

		SFDD		
	R. Cost %	W. Cost %	M. Cost %	SC Total %
option I	4	5	4^{nd}	4
option II	21	-1^{nd}	-11	4^{nd}
option III	-10	-4	18	2
		AOW		
	R. Cost %	W. Cost %	M. Cost %	SC Total %
option I	8	6	-3^{nd}	5
option II	11	2	-2^{nd}	4
option III	3	1	19	9
		PT		
	R. Cost %	W. Cost %	M. Cost %	SC Total %
option I	17	25	10	18
option II	7	6	11	8
option III	-4	-2	24	7
		IBMS		
	R. Cost %	W. Cost %	M. Cost %	SC Total %
option I	18	26	10	19
option II	6	6	11	8
option III	-4	-3	24	7

nd- means no significant difference at $p<0.05$

Table 5.13 Percentage change in impact due to RWM ISL for all three ordering policy scenarios

For option II scenario, the effect of RWM on total supply chain breach impact is an 8% mitigation when the breach is less disruptive and less recurring (IBMS) and all individual members of the chain enjoy mitigation as well. When the disruption duration is significantly increased (as in SFDD), the wholesaler and the manufacturer experiences a worsened RWM effect with an ensuing stabilisation and exacerbating effect respectively while the retailer on the other hand enjoys increased benefit. The resultant effect of having a significantly increased disruption duration on supply chain daily total average operating cost is that the RWM effect becomes of the stabilising type. A significant reduction in the RoC, however, only reduces and not diminishes the mitigating effect of RWM on total supply chain cost. The RWM effect on the manufacturer is diminished under this condition and becomes of a

stabilising nature while the retailer and wholesaler enjoys an increase and decrease respectively. Obviously from the result, there is no additional security measures required when the supply chain engages in RWM level as the impact of security breach is mitigated or at least stabilised even under increased disruption duration or RoC. However priority should be given to fortifying the breach corrective measures over the prevention and deterrence type, if at all any improvement in IT security is to be done.

Under option III, only the manufacturer enjoys a mitigation effect from RWM adoption while the retailer and the wholesaler both experiences an exacerbating effect when the breach is less disruptive with low RoC. The mitigation enjoyed by the manufacturer is large enough to produce a resultant positive effect on the total supply chain breach impact. Under significantly high disruption duration, the effect is made worse on the retailer and the wholesaler while the mitigation of the impact on the manufacturer is reduced but still high enough to ensure a resultant mitigating effect on the supply chain as a whole. Under significantly high RoC, however, there is an observed increase in RWM benefit to all supply chain agents as they enjoyed a mitigation effect, with the manufacturer seeing the highest benefit. Hence the supply chain as whole experiences an increased mitigation effect from RWM when the RoC is significantly increased. Consequently the recommendation is similar to that given in option II. Breach mitigation measures should be prioritised over preventive counterparts if any effort is to be driven towards IT security improvement.

5.4.4 Summary of Findings

The effect of each information sharing level (ISL) under information security breach scenario has been shown to differ for each supply chain agent and this effect changes based on the profile of the breach. It is clear from the result that for option I, RWM benefits the supply chain more than RW or WM does under a less disruptive and less recurring security breach scenario. However RW appears to fare better than RWM when the RoC is significantly high but RWM triumphs when the disruption duration is significantly high. WM appears to be the worst performer than the other two in a breach scenario. Under option II, RWM seems to outperform RW and WM in all scenarios of low or high disruption duration and RoC. Option III presents a different observation to those of options I and II. Here, RWM fares better than RW and WM under less disruptive and less recurring breach. However when the disruption

duration significantly increases, WM fares better than the other two in this category while RWM outperforms the other two under significantly increased RoC.

However a decision has to be made on which single ISL would be best suited to each ordering policy as only one ISL can be adopted at any particular time. Hence the strategy acceptance framework prescribed in Figure 5.2 can be applied here and the summary of the evaluation is shown in Table 5.14.

	Option I			Option II			Option III		
	RW	WM	RWM	RW	WM	RWM	RW	WM	RWM
n-BS Benefit	10%	1%	21%	2%	2%	7%	4%	5%	7%
BS Benefit	26%	0%	45%	10%	4%	24%	14%	22%	25%
Total Benefit	36%	1%	66%	12%	6%	31%	18%	27%	32%
Acceptable?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
ISB sharing with?	-	W	-	W, M	W	-	W	W	W
Incentive to?	-	W	-	M	-	-	-	W	-
IT priority	C	P&D	C	C	C	P&D	C	C	C

Table 5.14 Summary and implication of information sharing level to information security breach impact

The general observations here are as follows:

- RWM mode is the preferable sharing mode regardless of the type of ordering policy be it parameter based or batch ordering or the combination of both.
- Additional breach incentivisation is required for the wholesaler when the sharing mode does not include sharing the retailer's information under a parameter based or combined parameter based ordering policy.
- Under the batch ordering system, further incentivisation and ISB sharing can be prevented when the RW supply chain includes the manufacturer in information sharing.

This decision, according to this study, would differ under various supply chain structures. Having examined the isolating effect of structure and ISL separately, the next section takes a closer look at the joint effect under a breach scenario.

5.5 INTERACTION EFFECT BETWEEN ISL AND SUPPLY CHAIN STRUCTURE ON BREACH IMPACT

The magnitude of the interaction effect of ISL and structure on a breach with low disruption duration and low RoC, BP1 (IBMS), is shown in Appendix 5.1. That of a SFDD, AOW, PT and the aggregate effect under all four breaches is also shown in Appendix 5.1. The values in this Appendix are computed as described in section 5.3. A positive value reveals that the effect is beneficial while a negative value indicates a detrimental effect on cost performance. The nature of the interaction effect is shown in Appendix 5.2 and a detailed comparison between the state of interaction effect in a non-breach scenario and that in the various breach scenarios is also established in Appendix 5.2.

RW and RWM both represent a scenario where the retailer's inventory (including market demand) information is shared with upstream agents and examining the performance of RWM relative to RW is indicative of the effect of extending the information sharing to the manufacturer. WM represent the scenario where the retailer's information is not shared but the only partnership is between the wholesaler and the manufacturer. Therefore WM is indicative of the effect of not including retailer's information (especially market demand information) in the information sharing.

The combined strategy acceptance decision framework established in Figure 4.2 is applied here along with the framework shown in Figure 5.2. A summary of the aggregate benefit in a breach and non-breach scenario is shown for each combination scenario in the subsequent tables under each ordering policy. If the individual strategy performance is better than the performance of the combined strategies then such individual strategy would be considered the best alternative. Also included in the tables are the implication of such combinations or best alternative to supply partnership and ISM priorities. The decisions here are quite similar to the decisions in a non-breach scenario but the decision changes for some combinations after breach impact considerations. Those combinations or scenarios where the decision in a non-breach setting is different from information security breach settings is marked with an '*' symbol.

5.5.1 Summary and Implication of Interaction Effect under Parameter based ordering

Table 5.15 shows the summary of the acceptance and implication of the interaction effect on parameter based ordering policy (base stock policy) both under non-breach and breach scenarios.

	RW			WM			RWM		
	WH	MF	NT	WH	MF	NT	WH	MF	NT
n-BS Benefit (%)	12.3	12.5	4.2	2.2	2.8	1.1	23.4	23.5	14.4
BS Benefit (%)	34	33	4	2	-4	-4	64	65	34
Total Benefit (%)	46.3	45.5	8.2	4.2	-1.2	-2.9	87.4	88.5	44.4
Acceptable?	Yes	Yes	Yes	Yes*	No	No	Yes	Yes	Yes
Best Alternative	-	-	RW	-*	MF*	WM*	-	-	RWM
ISB sharing with?	-	-	M	W	W	W	-	-	M
Breach Incentive to?	-	-	M	-	-	-	-	-	M
IT priority	P&D	P&D	P&D	P&D	P&D	P&D	P&D	P&D	P&D

Table 5.15 Summary and implication of interaction effect in a parameter based ordering system

Under the parameter based policy, the benefit of combining the simplification strategy with sharing retailer's inventory information almost doubles when this information is extended to the manufacturer. Combining the networking strategy with sharing retailer's inventory information increases the benefit by more than 5 folds when the manufacturer is included. However, the manufacturer would require some form of incentivisation due to the negative impact of breach and would also require ISB sharing from the retailer. There is no benefit observed when manufacturing simplification or networking is combined with information sharing that does not include retailer's inventory information. However, some benefit is derivable when the wholesaling simplification is used instead.

Under each information sharing scenario, the wholesaling simplification strategy is best suited to RW and WM but the manufacturing simplification strategy is best suited to RWM. On the other hand, for supply chains pre-existing in wholesaler, manufacturer or network type structure would be most benefited by full information sharing strategy (RWM). Since more benefit is derived under BP3 than BP2, the priority of information security management would be breach prevention and deterrence over correction.

5.5.2 Summary and Implication of Interaction Effect under Batch Ordering Policy

Table 5.16 shows the summary of the acceptance and implication of the interaction effect on batch ordering policy (optimal EOQ model) both under non-breach and breach scenarios.

For a batch ordering system, the combination of any of the information sharing and structural reconfiguration strategies will produce improved cost performance especially in a breach scenario. Including the manufacturer in the information sharing strategy significantly increases the benefit of sharing the retailer's inventory information in combination with any structural reconfiguration strategies. Information sharing that does not involve retailer's information (WM mode) proves to be somewhat equally beneficial to the supply chain when combined with structural reconfiguration.

Supply chains existing in RW and RWM modes are best to adopt manufacturing simplification while WM supply chains are best to adopt wholesaling simplification. On the other hand, those pre-existing in Wholesaler and manufacturer type structures would be best served by adopting a full information sharing strategy (RWM) but those in network type structure would benefit more alone than in combination with any information sharing strategy.

The general implication of security breach to a batch ordering system is to focus more on breach prevention and deterrence than breach corrective measures.

	RW			WM			RWM		
	WH	MF	NT	WH	MF	NT	WH	MF	NT
n-BS Benefit (%)	2.9	5.6	-3.9	4.5	1.3	3.5	9	9.3	-1.9
BS Benefit (%)	50	58	27	53	39	48	66	69	36
Total Benefit (%)	52.9	63.6	23.1	57.5	40.3	51.5	75	78.3	34.1
Acceptable?	Yes*	Yes	Yes*	Yes	Yes*	Yes*	Yes	Yes	Yes*
Best Alternative	WH	-	NT	-	MF	NT	-	-	NT*
ISB sharing with?	M	-	W	-	-	-	-	-	W
Breach Incentive to?	M	-	W	-	-	-	-	-	W
IT priority	P&D	P&D	P&D	P&D	P&D	P&D	P&D	P&D	P&D

Table 5.16 Summary and implication of interaction effect in a batch ordering system

5.5.3 Summary and Implication of Interaction Effect under Combined Batch-and-Parameter based ordering

Table 5.17 shows the summary of the acceptance and implication of the interaction effect on combined batch-and-parameter based ordering policy (modified base stock policy) both under non-breach and breach scenarios. Under the combined ordering policy type, information sharing at any of the discussed levels combined with any of the structural reconfiguration strategies would provide benefit to the supply chain especially under security breach scenarios. Again the supply chain benefits more when the manufacturer is included in the sharing of retailer's inventory information. Information sharing that does not involve retailer's information (WM mode) provide more benefit than one that involves retailer's information especially in wholesaler or network type structure.

For supply chains currently in the RW or RWM mode of information sharing should consider manufacturing simplification while those existing in the WM should consider wholesaling simplification strategy.

	RW			WM			RWM		
	WH	MF	NT	WH	MF	NT	WH	MF	NT
n-BS Benefit (%)	5.9	8	1.7	11	4.8	8.1	9.7	10.3	4
BS Benefit (%)	38	45	1	56	35	46	50	51	30
Total Benefit (%)	43.9	53	2.7	67	39.8	54.1	59.7	61.3	34
Acceptable?	Yes	Yes	Yes*	Yes	Yes*	Yes	Yes	Yes	Yes
Best Alternative	-	-	NT	-	-*	-	-	-	-*
ISB sharing with?	-	-	M	-	W	-	-	-	W
Breach Incentive to?	-	-	M	-	W	-	-	-	W
IT priority	P&D	P&D	P&D	P&D	P&D	P&D	P&D	P&D	P&D

Table 5.17 Summary and implication of interaction effect in a batch-and-parameter based ordering system

On the other hand, supply chains existing in the wholesaler or network type structure should consider the WM information sharing mode while those in existing MF structure should consider full information sharing mode (i.e. RWM). For supply chains willing to reconfigure the supply chain and adopt a new information sharing strategy, the best option would be to adopt a wholesaling simplification strategy along with information sharing between the wholesaler and the manufacturer only.

Again, the general implication of security breach to a combined batch-and-parameter based ordering system is to focus more on breach prevention and deterrence than breach corrective measures.

5.6 DECISION MAKING FOR THE COMBINED IMPROVEMENT STRATEGIES

Considering the impact various information security breaches can have on supply chain performance, the decision is to adopt the two best improvement strategies (i.e. structural reconfiguration and information sharing) that will provide the best cost performance both in a non-breach and breach scenarios. Adopting both strategies at

the same time may be too overwhelming, therefore stepwise adoption may be the reasonable format for adoption. In stepwise adoption, the temptation might be to choose the individual best in each improvement category, however the individual best in each category does not correspond to synergy best when combined in the same supply chain. Therefore the decision to adopt should be based on a long term view that is if both would be adopted on the long run or if it is going to be just one improvement strategy. If the long term view is to adopt only one strategy, then the individual best would be ideal here. However, if both would be adopted on the long run, then the synergy best is more desirable than the combination of individual best. Having decided on the synergy best, this synergy could be decoupled and adopted in a stepwise manner as the supply chain chooses.

Table 5.18 shows the individual best for each improvement strategy under each ordering policy. The synergy between the two individual best is examined in the fourth column to see if it produces a positive result in the long run. The synergy of the two individual best is compared with the best alternative (i.e. synergy best) for each ordering policy in the sixth column to establish if there is a significant difference between the two synergy scenarios. Then the final decision as to which synergy of structure and information sharing level would be best suited for each ordering policy is determined.

	Structure Best	ISL Best	Good synergy?	Best Alternative	% difference	Decision
Option I	MF	RWM	Yes	RWM+MF	-	RWM+MF
Option II	NT	RWM	Yes	RWM+MF	44.2%	RWM+MF
Option III	WH	RWM	Yes	WM+WH	7.3%	WM+WH

Table 5.18 Decision making for combined strategies under each ordering policy with breach impact considerations

Although, the best cost performance in a non-breach scenario was under RWM in conjunction with wholesaling simplification, the decision was to select RWM and manufacturing simplification instead because there was no significant difference between the two combinations and the fact that manufacturing simplification and full integration (RWM) represented the individual best scenarios which means a stepwise

adoption can be done without compromising on optimal synergy between the two improvement strategies. Evaluating the impact of various breach scenarios has made the decision a bit clearer. The clear choice for parameter based policy of the base stock type is the combination between RWM and manufacturing simplification strategy as the result in Table 5.18 indicate.

Under the batch ordering and combined batch-and-parameter based ordering systems, the synergy between the individual best does not correspond to the synergy best. Therefore a long term view would see the adoption of RWM and manufacturing simplification over RWM and networking strategy for a batch ordering system. The long term view for a combined batch-and parameter based ordering system would be the combination of WM and wholesaling simplification strategy instead of the combination of wholesaling simplification and full integration strategy.

5.7 CONCLUSION AND MANAGERIAL IMPLICATION

This study has shown that, for the most part, structural reconfiguration and/or information sharing is beneficial both in a non-breach scenario and in a breach scenario. The impact of information security breach on supply chain performance will depend on the frequency of occurrence and the disruption duration of the breach when it occurs and different ordering policies are affected in different ways. The impact of information security breach increases along the upstream of the supply chain for a parameter based ordering system while this decreases as one goes upstream for a batch ordering system. The increasing impact has implication to supply chain members and some form of incentive should be provided as the breach did not occurs upstream but downstream and upstream agents should not have to pay dearly for disruption at the downstream end of the supply chain.

This study also provides justification for information security breach (ISB) sharing which has been called for by a few authors and has indicated where ISB priorities lie within the supply chain given various scenarios.

It has been demonstrated that the impact of information security breach, however, can be mitigated by improvement strategies such as supply reconfiguration and information sharing as shown in this study. The impact of security breach is significant enough to affect supply chain decisions with regards to information

sharing level choice or supply chain structure preference and it has been established that the decision to opt for certain ISL and structure combinations should not be taken without disruption impact considerations.

This study has also shown that these improvement strategies could be used as part of breach impact management strategy in addition to the ISM measures as they reduce the impact information security breach would otherwise have on a normal serial supply chain without information sharing.

The supply chain stands to benefit from a significant improvement in performance when these two strategies are used as long as the use and adoption is well informed. The study has highlighted the best information strategy given a specific supply chain structure and also the best structural reconfiguration strategy given a specific information sharing level that may be pre-existing in the supply chain. It has been shown that certain strategies fare better alone while others that are otherwise detrimental may yet prove beneficial when combined with other strategies.

So far this study has shown that supply chain improvement strategy decisions should not be made without information security breach considerations as disruption in information flow has huge implication to material flow which affects supply chain performance. However the author further posits that apart from the direct cost impact information security breach has on the supply chain inventory management performance, these breaches also introduce uncertainties in the supply chain. These uncertainties make it difficult to ascertain what future breach impact would be on the supply chain and hence might affect future performance of the supply chain. Due to the uncertainties associated with information security breach impacts and the indirect cost implication of this, the supply chain decision of which ordering policy, structure and/or information sharing level to adopt should not be made on only cost impact alone. The next study therefore incorporates the uncertainties of breach impact in making a final decision and this is discussed in the next chapter.

Chapter 6 : ENTROPY ASSESSMENT OF INFORMATION SECURITY BREACH AND THE DECISION FRAMEWORK

6.1 INTRODUCTION

The previous chapter has established that information security breach has a direct impact on the cost of managing inventory in the supply chain and that the magnitude and direction of this impact depends on the profile of the breach and the prevailing supply chain conditions (ordering policy, supply structure and ISL). This cost impact is quite uncertain in itself and the complexity of the operating condition of the supply chain could exacerbate this uncertainty and make it more difficult for supply chain managers to predict future impact. Being able to predict future impact is a form of control that any manager would like to have as this control is key to effective management. The presence of uncertainties makes management control all the more difficult. Higher levels of uncertainties mean higher level of controls is required while lower uncertainties require lesser control measures. This is considered in this study to be another form of security breach impact.

6.1.1 Research Motivation

This study uses the Theory of Entropy to capture breach impact uncertainties and provide an indication of the level of monitoring and review control required in the supply chain, if this needs to be increased or decreased. According to a guide written in 2010 by a group of the leading risk management organisations in the UK, The association of insurance and risk managers (AIRMIC); public sector risk management association (Alarm); and the institute of risk management (IRM), the need for monitoring and review is to ensure that that organisation can learn from past experience by monitoring risk performance (AIRMIC et al., 2010) and so they can reduce or eliminate future occurrence of a breach. Increasing the control level will incur additional cost and this should be judged based on the cost effectiveness which relates to the cost of increasing the control level compared to the derived risk reduction benefit. Therefore, a supply chain with high entropy would require high monitoring and review control levels because of the high uncertainty associated with predicting future impact, while that with low entropy would require low level of control. The impact of security breach on supply chain inventory management has been conceptualised in this study as a combination of the direct cost impact and the

indirect cost impact in the form of uncertainties. This approach has not been seen in past literature, at least to the author's knowledge.

The concept of entropy assessment itself is not novel as it has been used in other unrelated studies (Sivadasan et al. 2002) but this study is the first one to adapt it to information security breach impact studies. Apart from the uniqueness of the type of entropy assessment used here, this study purports to make further contribution to theory and practice by evaluating how structural reconfiguration and information sharing adds or reduces breach impact uncertainties and what the implication of this is to decision making.

6.1.2 Structure of Chapter

The rest of this chapter is structured as follows. Section 6.2 examines the level of uncertainty introduced by information security breach in a serial supply chain with no information sharing under all three ordering policy scenarios (base model). In section 6.3 and 6.4, the effect of structural reconfiguration and information sharing on uncertainty level is discussed respectively and the cost implication is shown along with an explanation of the decision framework. Section 6.5 examines the level of uncertainty associated with each breach when structural reconfiguration is combined with information sharing and its implication to cost and the decision framework which includes cost impact assessment and entropy assessment is drawn and explained.

6.2 ENTROPY ASSESSMENT OF BREACH IN THE BASE MODEL

The total entropy used in this assessment is obtained by the addition of the two types of entropy discussed in the methodology chapter which are nature entropy (for measuring nature uncertainty, *NU*) and extent entropy (for measuring extent uncertainty, *EU*). The *NU* is the uncertainty associated with not knowing whether there would be a negative impact or not, that is the 50/50 chance of a negative impact. This is also known as the uncertainty associated with knowing the 'nature' of the impact. The closer the probability of in-control (i.e. no negative impact observed) is to 50%, the closer *NU* is to 1. Also the further the probability of in-control is from 50% either increasing or decreasing, the closer *NU* is to 0. Hence the lower the *NU* score the more certain you are of either experiencing a negative impact or not, the higher the score the less certain you are. The *EU* on the other hand is the uncertainty

associated with the number of countable states of the impact when it is negative. This is also known as the uncertainty associated with knowing the 'extent' of the negative impact. Higher scores occur when the impact is spread over several countable states, and lesser scores occur over fewer countable states. Consequently the higher the probability of experiencing a negative impact over just one single state or none at all, the closer *EU* is to 0. The total entropy (*TE*) is the sum of nature entropy and extent entropy and this is used in this study's assessment. The entropy values themselves are additive.

To understand the landscape of breach impact uncertainty, the *NU*, *EU* and *TE* values of each performance measure (on-hand inventory and backlog quantity) is aggregated for each supply agent and for the entire supply chain. The TE values of each perfromance measure anf for each supply agent are categorised as low, medium and high uncertainty and ranked 1, 2, and 3 respectively as explained in section 3.8 of the methodology chapter.

6.2.1 Anatomy of the Breach Impact Uncertainty Associated with Ordering Option I

The entropy estimate for the two kinds of breach impact uncertainties of each breach type in an ordering option I supply chain is shown in Figure 6.1. It is clear from the figure that IBMS introduces the greatest level of uncertainty as evidenced by having the highest total entropy while AOW possess the least level of uncertainty. The uncertainty associated with predicting the nature of the impact whether the breach will be a positive one or a negative one (*NU*) is highest under IBMS followed by PT with AOW having the least. This of course is not surprising as the impact cost of IBMS on supply chain operational cost is marginal and therefore more difficult to ascertain if future attack will have a positive impact or a negative one. With PT having a higher cost impact than IBMS, the *NU* result shows that there is more certainty in predicting the nature of the future impact of PT than with IBMS. The certainty of the impact nature therefore increases as you go from IBMS to PT and to AOW and finally to SFDD. However the uncertainty associated with not knowing the extent of negative impact when the impact is negative (*EU*) is highest under SFDD followed by AOW. The *EU* value for IBMS and PT on the other hand is zero implying that the negative impact experienced occurred over only one countable state and not several states as those of SFDD and AOW suggest.

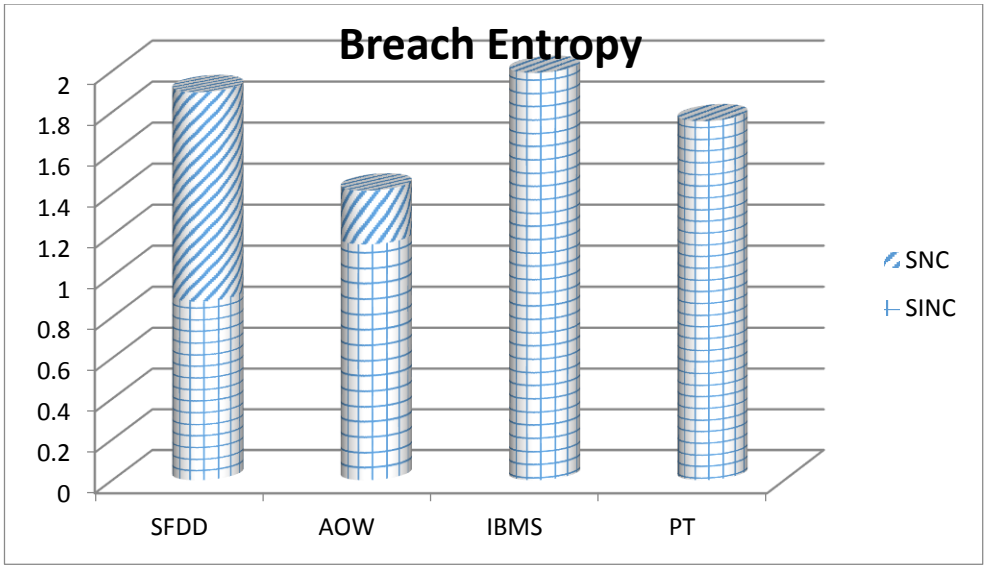


Figure 6.1 Level of supply chain uncertainty associated with each breach under Option I (SNC=EU; SINC=NU)

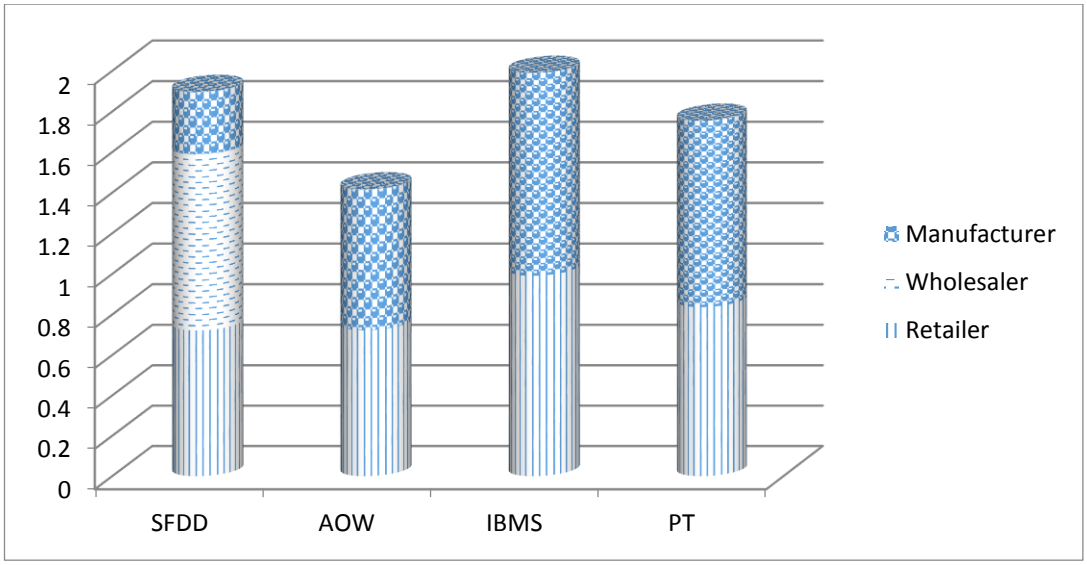


Figure 6.2 Level of uncertainty faced by supply agents for each breach under Option I

At the operational level, Figure 6.2 shows the total entropy level for each supply chain agent introduced by each security breach type. AOW, PT and IBMS breach types are considered less disruptive breaches because their disruption duration only last for an average of 1 day, while SFDD is considered highly disruptive because its disruption duration lasts for an average of five days. The impact of the less disruptive breaches (AOW, PT and IBMS) on the wholesaler performance is known with certainty, because the total entropy value is zero, and future impact is highly predictable. Their impact on the retailer and manufacturer however, is not quite

certain and therefore unpredictable. However, for the more disruptive breach with high disruption period (SFDD), there is reasonable amount of uncertainty in predicting future impact on all supply chain agents performance. Table 6.1 reveals a more complete picture of the entropy values for each security breach and the associated uncertainties for each supply chain member. The retailer apparently faces only one type of uncertainty which is that associated with not knowing the nature of the impact whether positive or negative (*NU*) for all security breach type. Although the value of the uncertainty associated with the *NU*mber of countable states of the impact when it is negative (*EU*) for all the security breaches is zero, the fact that the value of *NU* is greater than zero means the retailer experienced some negative impact in certain replication scenarios but this negative impact all occurred within one countable state. Hence the value of zero for *EU* here means that the retailer is very certain of the extent of the negative impact and is sure the future impact will exist within this state only. The uncertainty associated with not knowing the nature of the impact whether positive or negative is 0.72 for the retailer and this comes solely from the holding inventory performance. The value for its average backlog quantity performance were zero which means that retailer is certain of the nature of impact on backlog quantity performance. It can be seen from Appendix 4.1 that the impact of all four breach type was positive on the backlog cost performance of the retailer. Therefore given the same supply chain condition, the results of the *NU* suggest that the future cost impact of SFDD, AOW, IBMS and PT on the retailer's backlog cost will be positive. However, the impact of these breaches on its holding cost performance is quite uncertain and this uncertainty remains the same when the RoC or the disruption duration of the breach is increased or decreased.

Under SFDD breach the wholesaler is exposed to *EU* in its holding inventory performance with a value of 0.87. This seems to be the only type of uncertainty the wholesaler is faced with. This means that the predictability of the future impact of this breach on the holding inventory cost is uncertain with regards to the extent of negative impact.

Breach	Entropy Index	Retailer			Wholesaler			Manufacturer			SC
		Hold	Backlog	**R Total**	Hold	Backlog	**W Total**	Hold	Backlog	**M Total**	**Sum Total**
SFDD	*NU*	0.72	0.00	**0.72**	0.00	0.00	**0.00**	0.00	0.15	**0.15**	**0.88**
	EU	0.00	0.00	**0.00**	0.87	0.00	**0.87**	0.15	0.00	**0.15**	**1.02**
	TE	0.72	0.00	**0.72**	0.87	0.00	**0.87**	0.15	0.15	**0.31**	**1.90**
AOW	*NU*	0.72	0.00	**0.72**	0.00	0.00	**0.00**	0.00	0.00	**0.00**	**0.72**
	EU	0.00	0.00	**0.00**	0.00	0.00	**0.00**	0.26	0.00	**0.26**	**0.26**
	TE	0.72	0.00	**0.72**	0.00	0.00	**0.00**	0.26	0.00	**0.70**	**1.42**
IBMS	*NU*	0.99	0.00	**0.99**	0.00	0.00	**0.00**	0.00	1.00	**1.00**	**1.99**
	EU	0.00	0.00	**0.00**	0.00	0.00	**0.00**	0.00	0.00	**0.00**	**0.00**
	TE	0.99	0.00	**0.99**	0.00	0.00	**0.00**	0.00	1.00	**1.00**	**1.99**
PT	*NU*	0.84	0.00	**0.84**	0.00	0.00	**0.00**	0.00	0.92	**0.92**	**1.75**
	EU	0.00	0.00	**0.00**	0.00	0.00	**0.00**	0.00	0.00	**0.00**	**0.00**
	TE	0.84	0.00	**0.84**	0.00	0.00	**0.00**	0.00	0.92	**0.92**	**1.75**

Table 6.1 Entropy assessment of supply chain performance for option I under information security breach

Consequently, the impact will always be negative on holding cost but the extent of impact is uncertain. However the predictability of its impact on the wholesaler's backlog cost and ordering cost is quite certain. The *NU* and *EU* value for the backlog and the average order quantity is zero, which means the impact on backlog will always be positive and that on order quantity will always be negative and exist within only one countable state. For IBMS, PT and AOW, the predictability of their impact is certain for all three performance measures. The *NU* and *EU* value for the holding inventory, backlog and average order quantity is zero. The interpretation of this result, in combination with the result in Appendix 4.1, is that the impact of IBMS, PT and AOW will always be negative for the holding cost and this cost will exist within only one countable state. For the backlog cost and ordering cost, their impact will always be positive. Therefore comparing IBMS, PT and AOW, we see that the predictability of the impact on all three performance measures are very certain and the level of certainty remain the same even when the rate of occurrence of the breach is increased. From IBMS and SFDD, we see that increasing the disruption duration only increases the uncertainty associated with the extent of the impact on holding cost performance.

The holding cost performance of the manufacturer is affected by RoC and disruption duration as the result suggest. The *NU* of the impact of the less disruptive breaches on manufacturer's holding inventory performance is zero while the *EU* depends on the breach profile. The level of *EU* is not changed when there is a slight increase in RoC as shown by comparing IBMS and PT, but this uncertainty increases when there is significant increase in RoC although this uncertainty is still generally low. A similar observation is found for the disruption duration effect. The *EU* increases as you increase the disruption duration, although this is still categorised as low. For the manufacturer's backlog performance the uncertainty associated with breach impact is solely *NU* as opposed to *EU* for holding cost. The value of *NU* decreases from 1 in IBMS to 0.92 in PT and even further to zero in AOW. Therefore, the level of *NU* decreases when the RoC increases but the *EU* remains the same at the zero level. Also, increasing the disruption duration also reduces the *NU*, meaning the more disruptive the breach, the more certain you are of whether future breach impact will be either positive or negative.

6.2.2 Anatomy of the Breach Impact Uncertainty Associated with Ordering Option II

The type and level of uncertainty associated with the impact of each security breach on supply chain performance is shown in Figure 6.3. It is clear from the figure that the uncertainty associated with IBMS and PT is solely due to *NU* and does not include *EU* (*EU*). The impact of SFDD and AOW both face nature and extent uncertainties. While AOW faces low *EU* and high *NU*, SFDD faces a high *EU* and a low *NU*. Figure 6.4 reveals where the uncertainty hotspots lie within the supply chain. For the less disruptive breaches, the impact uncertainty is lowest at the retailer and this increases as one move upstream. However for the more disruptive breach (SFDD), the impact uncertainty is highest at the retailer and lowest at the wholesaler. Looking at the uncertainty associated with each performance measure for each supply chain agent paints a more holistic picture of the uncertainty hotspots and this is shown in Table 6.2.

From Table 6.2, it is evident that the uncertainty of the nature of the impact of the less disruptive breaches on retailer's holding inventory performance is low while that of the *EU* is nil. For the more disruptive breach, the *NU* is nil while that of the extent of negative impact is low. Therefore one is less certain of the nature of security breach impact for the less disruptive type and more convinced of the extent of negative impact. The retailer's backlog performance faces only *NU* under PT and IBMS but faces only *EU* under AOW and SFDD. Recall from Appendix 4.1 that the impact of SFDD and AOW is significantly large in percentage and in magnitude. Therefore there is higher certainty in predicting the nature of future impact than in predicting the extent of negative impact on retailer's backlog performance. However, there is higher uncertainty in predicting the extent of impact of SFDD on supply chain daily average operating cost than in predicting that of AOW.

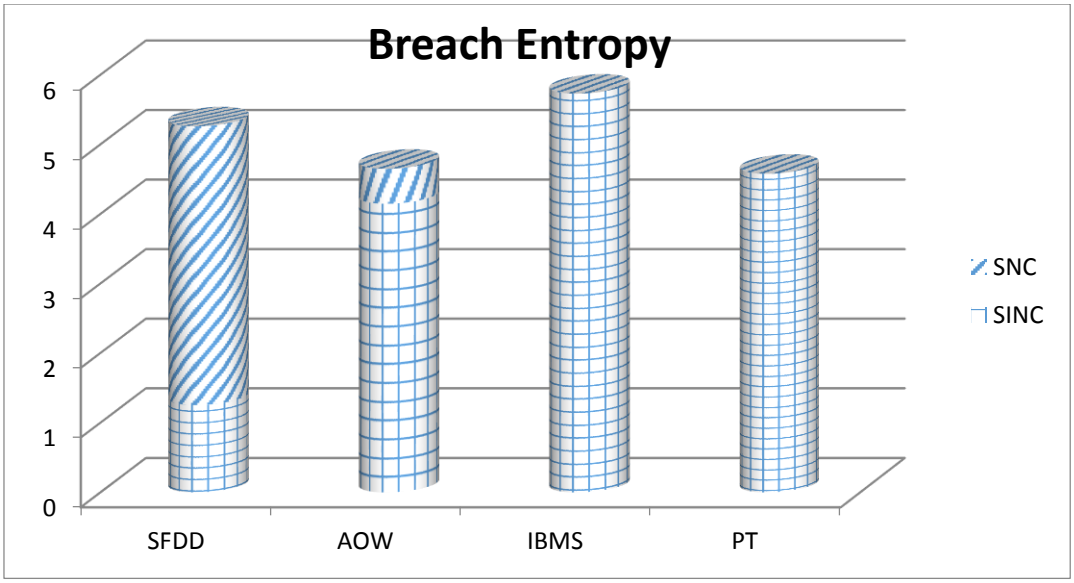


Figure 6.3 Level of supply chain uncertainty associated with each breach under Option II (SNC=EU; SINC=NU)

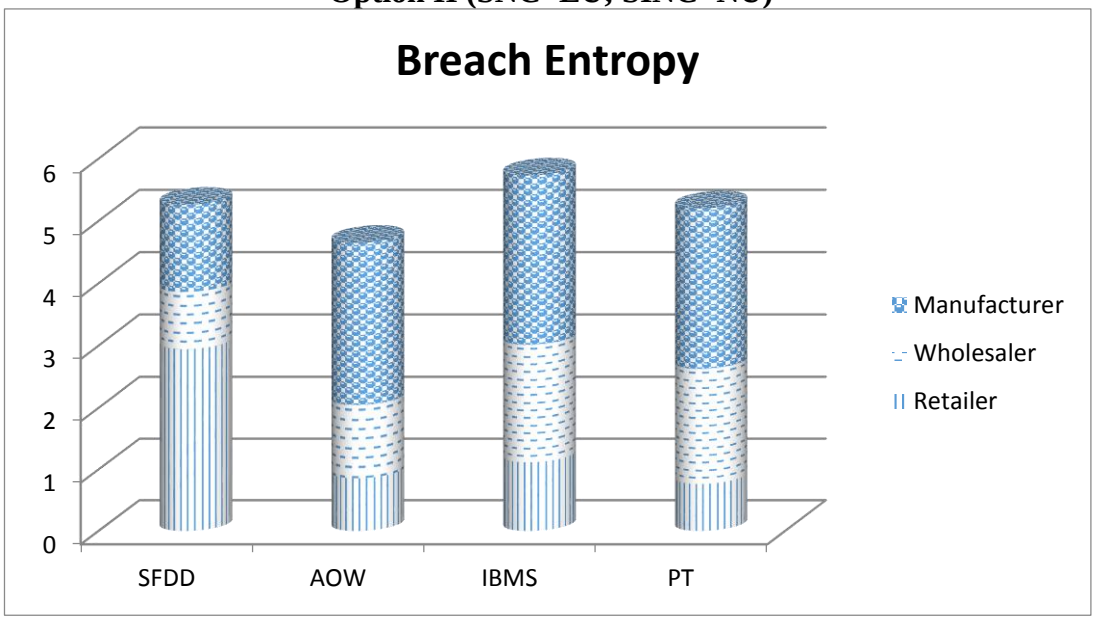


Figure 6.4 Level of uncertainty faced by supply agents for each breach under Option II

Breach	Entropy Index	Retailer			Wholesaler			Manufacturer			SC
		Hold	Backlog	**R Total**	Hold	Backlog	**W Total**	Hold	Backlog	**M Total**	**Sum Total**
SFDD	*NU*	0.00	0.00	**0.00**	0.00	0.00	**0.00**	0.84	0.26	**1.10**	**1.10**
	EU	0.26	2.68	**2.94**	0.35	0.57	**0.92**	0.14	0.00	**0.14**	**4.01**
	TE	0.26	2.68	**2.94**	0.35	0.57	**0.92**	0.98	0.26	**1.24**	**5.10**
AOW	*NU*	0.35	0.00	**0.35**	0.62	0.57	**1.19**	1.00	0.98	**1.98**	**3.52**
	EU	0.00	0.50	**0.50**	0.00	0.00	**0.00**	0.00	0.00	**0.00**	**0.50**
	TE	0.35	0.50	**0.86**	0.62	0.57	**1.19**	1.00	0.98	**1.98**	**3.52**
IBMS	*NU*	0.35	0.76	**1.12**	0.87	0.76	**1.63**	1.00	1.00	**2.00**	**4.75**
	EU	0.00	0.00	**0.00**	0.00	0.00	**0.00**	0.00	0.00	**0.00**	**0.00**
	TE	0.35	0.76	**1.12**	0.87	0.76	**1.63**	1.00	1.00	**2.00**	**4.75**
PT	*NU*	0.50	0.26	**0.77**	0.94	0.57	**1.51**	0.98	0.97	**1.95**	**4.23**
	EU	0.00	0.00	**0.00**	0.00	0.00	**0.00**	0.00	0.00	**0.00**	**0.00**
	TE	0.50	0.26	**0.77**	0.94	0.57	**1.51**	0.98	0.97	**1.95**	**4.23**

Table 6.2 Entropy assessment of supply chain performance for option II under information security breach

The uncertainties associated with the nature and extent of security breach impact on wholesaler's holding inventory performance is similar to that of the retailer, only higher. IBMS, PT and AOW only pose a *NU* to holding cost of the wholesaler while SFDD only poses an *EU*. Therefore more information is required in controlling the nature outcome of the less disruptive breaches while more information is required to gain control over the more disruptive types. For the wholesaler's backlog performance, the uncertainty associated with the impact of the less disruptive breaches is only of the *NU* type while SFDD is only of the *EU* type.

The *NU* value for the less disruptive breaches on Manufacturer's holding inventory performance is either maximum or near maximum. A value of 1 indicates that half of the replication scenario was positive impact and the other half was negative. This shows there is the highest uncertainty in predicting the nature of the future impact of AOW, PT and IBMS on manufacturer's holding inventory performance. However a *EU* value of zero reveals that the extent of negative impact is highly predictable. For the more disruptive breach type, SFDD, the *NU* is also quite high and the extent of negative impact is known with a reasonably good level of certainty as *EU* value is quite low. Like the holding inventory performance of the manufacturer, the impact of the AOW, PT and IBMS on manufacturer's backlog performance indicates near maximum uncertainty in knowing the nature of impact and zero uncertainty (i.e maximum certainty) in predicting the extent of negative impact. For SFDD, the result shows that the extent of future impact is highly predictable but that of the nature of future impact is somewhat uncertain.

6.2.3 Anatomy of the Breach Impact Uncertainty Associated with Ordering Option III

Clearly from Figure 6.5, the aggregate *EU* value for the supply chain increases as the RoC of the breach increases, however, the *NU* value decreases as RoC increases. Consequently, increasing the RoC of a breach increases the *EU* of the impact but decreases the *NU*. We also see by comparing IBMS and SFDD that increasing the disruption duration increases the *EU* but reduces the *NU*. Therefore the negative impact of a breach with an increased disruption period on supply chain performance will be less predictable, and you can be more certain of the nature of its impact, than that of a less disruptive one. At the supply chain agent level, Figure 6.6 reveals that the uncertainty of predicting the impact of security breach is highest at the

manufacturer for all breach type. However, between the retailer and the wholesaler, the profile of the breach determines which one is greater. Again, a clearer picture is painted by Table 6.3 showing where these uncertainties lie.

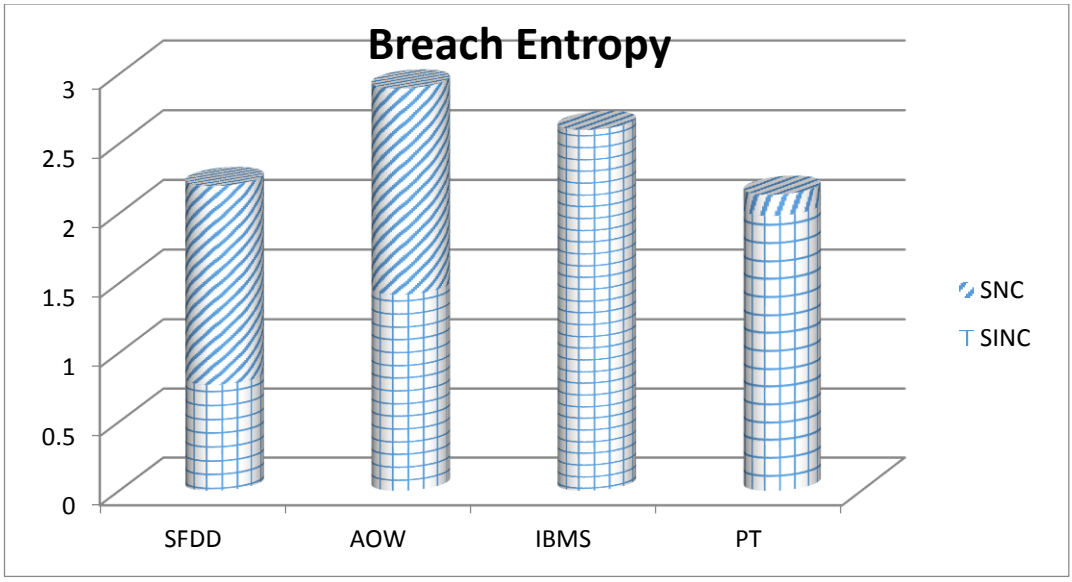


Figure 6.5 Level of supply chain uncertainty associated with each breach under Option III (SNC=EU; SINC=NU)

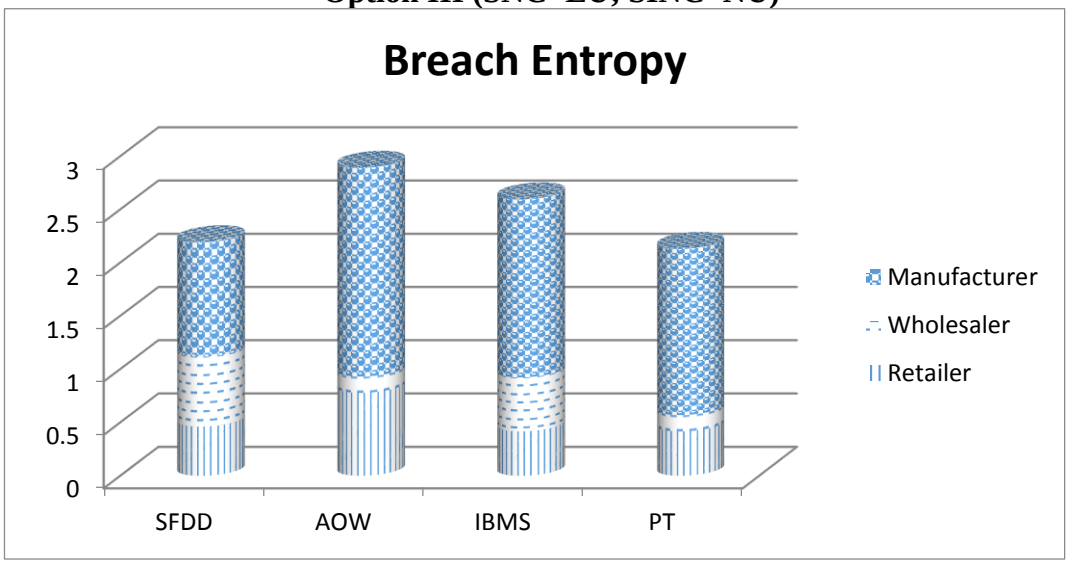


Figure 6.6 Level of uncertainty faced by supply agents for each breach under Option II

Breach	Entropy Index	Retailer			Wholesaler			Manufacturer			SC
		Hold	Backlog	**R Total**	Hold	Backlog	**W Total**	Hold	Backlog	**M Total**	**Sum Total**
SFDD	*NU*	0.00	0.15	**0.15**	0.00	0.00	**0.00**	0.00	0.15	**0.15**	**0.30**
	EU	0.15	0.00	**0.15**	0.50	0.00	**0.50**	0.77	0.00	**0.77**	**1.42**
	Total	0.15	0.15	**0.30**	0.50	0.00	**0.50**	0.77	0.15	**0.92**	**1.72**
AOW	*NU*	0.00	0.00	**0.00**	0.00	0.00	**0.00**	0.15	0.00	**0.15**	**0.15**
	EU	0.62	0.00	**0.62**	0.00	0.00	**0.00**	0.86	0.00	**0.86**	**1.48**
	Total	0.62	0.00	**0.62**	0.00	0.00	**0.00**	1.01	0.00	**1.01**	**1.63**
IBMS	*NU*	0.00	0.26	**0.26**	0.00	0.35	**0.35**	0.57	0.96	**1.53**	**2.14**
	EU	0.00	0.00	**0.00**	0.00	0.00	**0.00**	0.00	0.00	**0.00**	**0.00**
	Total	0.00	0.26	**0.26**	0.00	0.35	**0.35**	0.57	0.96	**1.53**	**2.14**
PT	*NU*	0.00	0.26	**0.26**	0.00	0.00	**0.00**	0.26	1.00	**1.26**	**1.52**
	EU	0.00	0.00	**0.00**	0.00	0.00	**0.00**	0.15	0.00	**0.15**	**0.15**
	Total	0.00	0.26	**0.26**	0.00	0.00	**0.00**	0.41	1.00	**1.41**	**1.67**

Table 6.3 Entropy assessment of supply chain performance for option III under information security breach

For the retailer's holding inventory performance, there is no uncertainty associated with predicting the nature of impact for all considered breach types. However SFDD and AOW have associated *EU* with *EU* greater in AOW than in SFDD. There is no uncertainty in predicting the extent of future impact on retailer's backlog performance for all security breach type, but there exist a low level of uncertainty in predicting the nature of future impact with AOW having no uncertainty at all.

The wholesaler under option III experiences no uncertainty, nature or extent, in the area of holding inventory for the less disruptive breaches but experiences only a low level of *EU* under the more disruptive breach. For the wholesaler's backlog performance, only the IBMS breach has an associated *NU* while the other breach types have zero uncertainty associated with them.

There is of course greater uncertainties at the manufacturer's end than the rest of the supply chain. Comparing the entropy scores of AOW, PT and IBMS, we see that as RoC increases, the *NU* decreases and the *EU* increases for the manufacturer's holding inventory performance. For the disruption duration effect on the holding cost performance uncertainty, increasing the duration of disruption leads to reduction in *NU* and increase in *EU*. With respect to the manufacturer's backlog performance, the uncertainty associated with the breach impact is mainly due to the nature type and not the extent type. IBMS and PT poses the highest *NU* uncertainty while SFDD poses a low uncertainty and AOW poses no uncertainty at all.

6.3 STRUCTURE EFFECT ON UNCERTAINTY LEVEL OF BREACH IMPACT

The result of the entropy values of each performance measure for all three supply chain agents under the structure scenarios for ordering options I, II and III are categorised and rated as explained in the methodology chapter (section 3.8.5). The rating outcome can be found in Appendix 6.1. The detailed analysis in section 6.2 was to provide a sense of how to critically analyse the entropy assessment at the operational level by decomposing the entropy measures and examining how each performance measure is affected and the implication thereof. However in this section, the aim is to establish how the entropy level (uncertainty category) changes from the base model to the other structure types. Therefore the relative change in

uncertainty level when each structure scenario is compared with the base model scenario for all three ordering options is the primary concern here.

This relative change is obtained by noting what the uncertainty rating in the base model is and computing how much higher or lower the rating of the corresponding structure is. For instance if the uncertainty rating in the base model is 1 (i.e. low uncertainty) and the rating in, say, the WH structure is 2 (i.e. medium uncertainty), the relative change is 1-2 = -1 (minus means increase in uncertainty). This means that WH structural reconfiguration increases the impact uncertainty by one level (from low to medium). If the rating in the WH structure was 3 (i.e. high uncertainty) then the relative change is 1-3 = -2, meaning wholesaling simplification would increase the uncertainty by two levels (from low to high). The sign indicate the direction of the change while the values indicate the magnitude of the change. A positive value means the structure effect reduces the uncertainty level while a negative value indicates otherwise. A value of zero reveals that structural reconfiguration does not affect the level of uncertainty.

6.3.1 Entropy Analysis of WH Effect

The result of the relative change in uncertainty level due to wholesaling simplification can be found in Table 6.4.

From the table, the influence of WH on uncertainty level is of an exacerbating nature (up one level) to the supply chain under less disruptive breaches (BP1) but becomes a stabilising effect when RoC of breach is greatly increased. However, the wholesaling simplification strategy has an uncertainty mitigation benefit with one level decrease in uncertainty level. At the operational level, the wholesaler experiences a similar effect while the retailer is unperturbed by the strategy. The manufacturer, under this strategy, however is unperturbed by a less disruptive breach but appear to have lower uncertainty level with the strategy when RoC and disruption duration are high. Decomposing the result by examining the *NU* (nature uncertainty) and *EU* (extent uncertainty) performance reveals that the uncertainty mostly associated with this structure is of the nature type, although this is categorised as low. Therefore it can be concluded that changing to a WH structure configuration under the base stock policy (option I) does not add to the supply chain

complexity and better control can be derived when breaches with high disruption duration and RoC occur.

	SFDD			
	Retailer	Wholesaler	Manufacturer	SC Total
option I	0	1	1	1
option II	0	1	0	0
option III	1	0	0	1
	AOW			
	Retailer	Wholesaler	Manufacturer	SC Total
option I	0	0	1	0
option II	0	0	0	0
option III	0	0	0	1
	PT			
	Retailer	Wholesaler	Manufacturer	SC Total
option I	0	0	0	0
option II	0	0	0	0
option III	0	-1	0	0
	IBMS			
	Retailer	Wholesaler	Manufacturer	SC Total
option I	0	-1	0	-1
option II	0	0	0	0
option III	0	0	0	0

Table 6.4 WH effect on information security breach impact uncertainty level

Under the batch ordering system, wholesaling simplification strategy does not add to supply chain complexity and a stabilising effect is achieved under all breach scenarios. The wholesaler, however, enjoys a reduction in uncertainty by one level under BP1. The other agents experience an uncertainty level stabilising effect.

For the combined policy, the uncertainty associated with the impact of BP1 on the supply chain is stabilised under the WH strategy and there is further reduction of uncertainty by one level under BP2 and BP3. However the retailer benefits more under BP3 and the wholesaler benefit less under PT and the manufacturer is unperturbed.

6.3.2 Entropy Analysis of MF Effect

The result of the relative change in uncertainty level due to wholesaling simplification can be found in Table 6.5.

	SFDD			
	Retailer	Wholesaler	Manufacturer	SC Total
option I	0	0	1	1
option II	0	1	0	0
option III	0	0	-1	0
	AOW			
	Retailer	Wholesaler	Manufacturer	SC Total
option I	0	0	1	0
option II	0	0	0	0
option III	1	0	1	1
	PT			
	Retailer	Wholesaler	Manufacturer	SC Total
option I	0	0	0	0
option II	0	0	0	0
option III	0	0	0	0
	IBMS			
	Retailer	Wholesaler	Manufacturer	SC Total
option I	0	-1	-1	-1
option II	0	0	0	0
option III	0	0	0	0

Table 6.5 MF effect on information security breach impact uncertainty level

Simplifying the manufacturer tier in a supply chain using parameter based ordering result in an increase in uncertainty by one level from nil to low under BP1 but in a BP2 scenario the uncertainty level remains the same. However, under a BP3, the simplification strategy reduces the uncertainty by a level from low to nil. At the operational level, the uncertainty level at the retailer is unperturbed by this simplification strategy but the manufacturer and wholesaler are affected differently depending on the profile.

Manufacturing simplification in a batch ordering supply chain does not affect the uncertainty level of the supply chain regardless of the breach profile. The supply agents are also not affected, except for the wholesaler where uncertainty is reduced by a level.

With the combined policy type, simplifying the ‘make’ process, i.e. manufacturing tier, does not change the impact uncertainty level in the supply chain under any security breach scenario except for a decrease in uncertainty when the breach has high RoC. At the supply agent level, the uncertainty level of the manufacturer is increased by a level under BP3 but reduced by a level under BP2. Hence there is observed benefit for the manufacturer from simplifying the make process only under breach with high RoC.

6.3.3 Entropy Analysis of NT Effect

The result of the relative change in uncertainty level due to wholesaling simplification can be found in Table 6.6.

NT	SFDD			
	Retailer	Wholesaler	Manufacturer	SC Total
option I	0	1	1	1
option II	0	1	0	0
option III	1	0	0	1
	AOW			
	Retailer	Wholesaler	Manufacturer	SC Total
option I	0	0	1	0
option II	0	0	0	0
option III	0	0	0	1
	PT			
	Retailer	Wholesaler	Manufacturer	SC Total
option I	0	0	0	0
option II	0	0	0	0
option III	0	-1	0	0
	IBMS			
	Retailer	Wholesaler	Manufacturer	SC Total
option I	0	-1	0	-1
option II	0	0	0	0
option III	0	0	0	0

Table 6.6 MF effect on information security breach impact uncertainty level

Networking, as defined in this study, increases the total supply chain uncertainty associated with the impact of a breach of the type BP1 under a parameter based policy. The effect under a BP2 is of a stabilising type and that under BP3 is a mitigating type with one level decrease in uncertainty. The wholesaler is affected in a similar way but the retailer is unaffected under any of the breach profiles. The manufacturer on the other hand benefits under BP2 and BP3 with a level reduction in uncertainty under both profiles.

Again the supply chain is unperturbed when networking is undertaken in a batch ordering supply system. The wholesaler can only benefit with a level reduction in uncertainty when the disruption duration is high.

Considering a supply chain using the combined batch-and-parameter based ordering policy, the effect of networking stabilises the impact uncertainty of a breach with profile of the BP1 type but brings about a reduction in uncertainty by one level under

BP2 and BP3. The uncertainty level of the impact of any breach on manufacturer's performance under this strategy is not affected.

6.3.4 Summary and Cost Implication of Entropy Change Due to Structural Reconfiguration

The increase in uncertainty level means the new reconfigured supply chain structure needs to increase its monitoring and review level to match the uncertainty level in the pre-existing serial structure. This would require additional cost to the supply chain. A decrease in uncertainty level as a result of reconfiguration means the new supply chain structure can afford to either maintain the status quo or reduce the monitoring and review effort. This means the reconfigured supply chain can save cost that would have been needed by the pre-existing serial structure to increase its monitoring level to the one found after reconfiguration. Therefore the cost of additional monitoring and review should be compared to the mitigation benefit provided by the new structure. If the additional cost due to increased uncertainty is larger than the mitigation benefit derivable, then the new structure is considered unproductive and should be disqualified. However if the additional cost in monitoring and review as a result of increased uncertainty is less than the mitigation benefit, then the proposed new structure is considered productive and a decision can be made to reconfigure into this structure.

It is imperative for any organisation, given its specific needs for security, to implement proper security control measures or countermeasures. These include but not limited to Personnel Security; Physical and Environmental Protection; Contingency Planning; Configuration Management; Maintenance; System and Information Integrity; Media Protection; Incident Response; Awareness and Training (Ouyang, 2012b). These controls also have various sub categories of controls and they all require monitoring and review. Examples of some of the monitoring and review measures extracted from Ouyang (2012b) include:

- Monitor & track inventory & maintenance records
- Monitor & track service level and mean time between failure (MTBF) of system or components
- Contingency plan testing which includes walkthroughs (tabletop exercise), checklist, simulation, or full interruption test,
- Ensure remote maintenance is performed under monitor & control, and it is executed in accordance to change control process
- Ensure only authorized personnel can access systems

- Keep track of authorized 3rd party maintenance personnel and document actions performed.
- Ensure timely maintenance
- Define & monitor service level agreements (SLAs)
- Keep or arrange supply chain of spare parts for mission critical components.
- Issuance of security alerts and advisories (situation awareness) periodically and as at when required
- Information records handling and retention
- System log retention
- Monitor user access (non-privilege & privilege).
- Security functionality verification
- Security audits for compliance.
- Periodic security assessments (to identify potential vulnerabilities & mitigate potential exposure).
- Periodically reviewing levels of security response measures to maintain security posture.

According to a classification by Alshboul (2010), when an organisation implements 0-49% of the measures and countermeasures, the security level is said to be high. When it implements 50-79% or 80-100% then the security level is considered moderate or high respectively. Since each breach is unique in the way it is perpetrated, the focus of monitoring and review measures would also be unique or specific to each breach. The specificity of monitoring and review activities means there would be different measures or controls for different breach types. To know the exact requirement i.e. the level of control required is essential. The argument here is that since entropy level is reflective of the amount of information needed to manage and control a particular system, acquiring this information will incur certain costs. It therefore follows that higher entropy means higher level of information required to have control over the system (i.e. higher monitoring and review level), hence higher associated cost. Since the actual cost of increasing monitoring and control level would vary for different organisations, the following assumptions are made to help quantify this cost implication:

Let;

S = the cost associated with monitoring and controlling the SFDD breach,
A= the cost associated with monitoring and controlling the AOW breach,
P = the cost associated with monitoring and controlling the PT breach, and
I = the cost associated with monitoring and controlling the IBMS breach.

The logic follows that a level increase in uncertainty (low to medium or medium to high) corresponds to a level increase in the monitoring and control level required to match the new level of uncertainty. If the cost associated with increasing the monitoring and control by one level is represented by subscript 1 and an increase by two levels is represented by subscript 2, then S_i, A_i, P_i, I_i are the average daily cost associated with increasing the monitoring and review by i level needed for SFDD, AOW, PT and IBMS respectively.

where i = 1, 2, 3.

For example, S_1 would be the daily average cost associated with increasing the monitoring and review level of SFDD by one, while P_2 would be that for increasing the monitoring and review level of PT by two.

The result in Table 6.7 reveals the cost implication of structural reconfiguration from a serial type to a wholesaler, manufacturer and network types based on the monitoring and review level change required. The result in the table shows the cost associated with each entropy level increase or decrease for all breach types and the cost of all the breaches is added up to give the total cost which is also termed the structural reconfiguration uncertainty cost implication. A positive value indicates a cost savings as a result of reduction in monitoring and review level while a negative value indicates an additional cost required as a result of increased monitoring and review level.

It is clear from Table 6.7 that, under the parameter based policy such as the base stock policy (option I), structural reconfiguration in the supply chain would have a cost implication with magnitude S_1-I_1 which can be cost saving (if $S_1>I_1$) or added cost (if $S_1<I_1$) regardless of the reconfiguration type. On the other hand, under a batch ordering system (option II), structural reconfiguration strategy neither requires additional monitoring and review cost nor saves the supply chain the associated cost. Under the combined policy system (option III), cost savings equivalent to one level decrease can be derived under SFDD and AOW breach when wholesaling simplification or networking strategy is adopted but manufacturing simplification only saves cost when AOW breach is concerned.

	Monitoring and Review Cost Implication		
Option I	WH	MF	NT
SFDD	S_1	S_1	S_1
AOW	-	-	-
IBMS	$-I_1$	$-I_1$	$-I_1$
PT	-	-	-
Extra Cost Saving	**$S_1 - I_1$**	**$S_1 - I_1$**	**$S_1 - I_1$**
Option II	WH	MF	N
SFDD	-	-	-
AOW	-	-	-
IBMS	-	-	-
PT	-	-	-
Extra Cost Saving	**-**	**-**	**-**
Option III	WH	MF	N
SFDD	S_1	-	S_1
AOW	A_1	A_1	A_1
IBMS	-	-	-
PT	-	-	-
Extra Cost Saving	**$S_1 + A_1$**	**A_1**	**$S_1 + A_1$**

Table 6.7 Cost implication of structural reconfiguration effect on uncertainty level

6.3.5 Decision Framework for Supply Chain Structure Reconfiguration

Remember this study is trying to assess the benefit of restructuring to information security impact and what is being examined is the relative performance of each structure to a serial type structure. The question then begs which would be the ideal configuration to choose and what 'extra' control would be needed or not needed when restructuring takes place. The word 'extra' was carefully selected because the serial supply chain has pre-existing security control priorities depending on the ordering policy, however the effect of changing the structure is examined to see how the control level and priority changes in a reconfigured setting. Therefore the decision framework combines the direct cost impact assessment and indirect cost impact (entropy level change) assessment in deciding which structure holds the best benefit. The combined assessment can be found in Table 6.8. To arrive at the best decision, the following steps are taken:

i. Compute the benefit of the improvement strategy in a non-breach scenario.

ii. Compute the mitigation benefit of the improvement strategy under various information security breach scenarios.
iii. Compute the aggregate benefit by adding the improvement benefit in a non-breach scenario and the various breach scenarios.
iv. Estimate the aggregate cost implication of changing the monitoring and review level in the supply chain (if cost implication is positive, then it is considered cost saving benefit; but if cost implication is negative, then it is considered to be an additional cost).
v. Compute the overall benefit by adding i, ii, iii and iv.
vi. To decide on the ideal configuration the one with the highest cost benefit is selected

The aggregate structural reconfiguration benefit in a non-breach scenario (n-BS) and in various breach scenarios (BS) under each ordering policy has been established in section 5.3.4. This is extracted and included in Table 6.8. A 1% increase or decrease in benefit is equivalent to £3.97 (for option I); £3.10 (for option II); £3.00 (for option III).

From Table 6.8, it is clear that, under the parameter based policy, the WH and NT structures exacerbates the aggregate daily cost performance of the supply chain in both non-breach and breach scenarios by 3% and 6% respectively while MF improves it by 4%. Entropy assessment however indicate that the effect of all three strategies is similar with an implied cost of S_1 - I_1. Therefore, the MF structure can be adopted if and only if 4% + S_1 is significantly greater than I_1. Otherwise the serial structure is better off than when reconfiguration into any of the structures discussed.

Under the batch ordering system, the supply chain need not worry about changing the monitoring and review level and the final decision can be based on the direct cost impact alone. Therefore, having considered the direct and indirect cost implications of structural reconfiguration, the networking strategy appears to be the best strategy under normal and disruption circumstances.

With the combined ordering system, structural reconfiguration provides additional cost savings especially under highly disruptive or highly recurring breach. Since the wholesaling simplification strategy offers the best performance under the direct impact assessment and joint best under the indirect cost assessment, it is very clear

that WH structure is the ideal reconfiguration choice for the combined batch-and-parameter ordering system.

Option I	WH	MF	NT
Aggregate benefit (n-BS and BS)	-3%	4%	-6%
Monitoring and review cost	S_1 - I_1	S_1 - I_1	S_1 - I_1
Overall benefit	-3% + S_1 - I_1	4% + S_1 - I_1	-6% + S_1 - I_1
Decider	Max (WH, MF, N)		
Final Decision	No reconfiguration, if MF: 4% + S_1 >> I_1, else MF		
Option II	WH	MF	NT
Mitigation benefit	49.8%	47.7%	50.9%
Monitoring cost	-	-	-
Overall benefit	49.8%	47.7%	50.9%
Decider	Max (WH , MF, NT)		
Final Decision	NT		
Option III	WH	MF	NT
Mitigation benefit	29.0%	21.7%	25.0%
Monitoring cost	S_1 + A_1	A_1	S_1 + A_1
Overall benefit	29% + S_1 + A_1	21.7% + A_1	25.0% + S_1 + A_1
Decider	Max (WH, MF, NT)		
Final Decision	WH		

1% is equivalent to £3.97 (for option I); £3.10 (for option II); £3.00 (for option III).

Table 6.8 Decision framework for structural reconfiguration under each ordering policy

6.4 INFORMATION SHARING LEVEL EFFECT ON UNCERTAINTY LEVEL OF BREACH IMPACT

The result of the rating outcome for information sharing level effect on ordering systems I, II and III can be found in Appendix 6.2. The aim of this section is to establish the relative change in entropy level due to adopting various information sharing strategies and to examine the cost implication to monitoring and review

activities. To the end of understanding how this can affect information sharing adoption decision. An examination of this result in the manner with which section 6.3 was examined will provide the same level of insight for each ISL.

6.4.1 Entropy Analysis of RW Effect

The result of the relative change in uncertainty level due to information sharing between the retailer and wholesaler only can be found in Table 6.9.

	SFDD			
	Retailer	Wholesaler	Manufacturer	SC Total
option I	0	1	0	0
option II	0	-1	-2	-1
option III	0	0	0	0
	AOW			
	Retailer	Wholesaler	Manufacturer	SC Total
option I	0	-1	0	-1
option II	-1	0	-1	0
option III	1	0	0	1
	PT			
	Retailer	Wholesaler	Manufacturer	SC Total
option I	0	-1	1	0
option II	0	0	-1	0
option III	1	-1	0	1
	IBMS			
	Retailer	Wholesaler	Manufacturer	SC Total
option I	0	-1	1	-1
option II	0	0	-1	0
option III	0	0	0	0

Table 6.9 Effect of RW mode on information security breach impact uncertainty level

Under the parameter based ordering system, information sharing between the retailer and the wholesaler alone in the supply chain increases the level of breach impact uncertainty by one under BP1 and BP2. However, under BP3, there is no difference between the uncertainty level in the non-information sharing mode (NI) and the RW mode. The uncertainty level remains unchanged for the retailer under all three breach profiles while that of the wholesaler is increased by one level under BP1 and BP2 but decreased by one level under BP3. The manufacturer only derived a one level reduction in uncertainty level under BP1 but observed no changes to uncertainty level under high disruption duration or RoC.

For the batch ordering system, RW effect cause a stabilisation of the uncertainty level under BP1 and BP2 but increases it under BP1 by one level (from low to

medium). For the respective supply agents, the wholesale experience a similar effect to that of the entire supply chain but the retailer is unaffected except under BP2 where a one level increase is observed. The manufacturer is worst affected with a one level increase under BP1 and BP2 and a two level increase under BP3. The manufacturer happens to be the hotspot for uncertainty in such supply chains using the batch ordering policy.

With the combined policy type, there is an observed one level reduction in uncertainty level after RW information sharing mode adoption only under BP2. On the other hand, the manufacturer and wholesaler are unaffected under all three scenarios while the retailer only benefits under BP1.

6.4.2 Entropy Analysis of WM Effect

The result of the relative change in uncertainty level due to information sharing between the wholesaler and manufacturer only can be found in Table 6.10.

At the supply chain level, under a parameter based ordering system, adopting the WM mode of information sharing worsens the uncertainty by a level when the supply chain faces a breach of BP1 type but there is no apparent effect on the uncertainty level when the disruption duration and RoC are increased significantly. However at the level of the individual supply agents, only the manufacturer enjoys a reduced uncertainty level under BP2 and BP3 while the other agents are unaffected regardless of the breach profile.

Under the batch ordering policy, the uncertainty level in the supply chain and at each individual agent is unaffected by a WM configuration. Hence no change in monitoring and review level required.

With the combined policy, the supply chain uncertainty level is only affected under PT breach and this is due to the fact that WM mode reduces the entropy level at the retailer (from low to nil) under this breach. The manufacturer is unperturbed by the WM mode regardless of the breach profile but the wholesaler is affected negatively under BP2 with a level increase in uncertainty

.

	SFDD			
	Retailer	Wholesaler	Manufacturer	SC Total
option I	0	0	1	0
option II	0	0	0	0
option III	0	0	0	0
	AOW			
	Retailer	Wholesaler	Manufacturer	SC Total
option I	0	0	1	0
option II	0	0	0	0
option III	0	-1	0	0
	PT			
	Retailer	Wholesaler	Manufacturer	SC Total
option I	0	0	0	0
option II	0	0	0	0
option III	1	0	0	1
	IBMS			
	Retailer	Wholesaler	Manufacturer	SC Total
option I	0	0	0	-1
option II	0	0	0	0
option III	1	0	0	0

Table 6.10 Effect of WM mode on information security breach impact uncertainty level

6.4.3 Entropy Analysis of RWM Effect

The result of the relative change in uncertainty level due to information sharing between the wholesaler and manufacturer only can be found in Table 6.11.

The effect of full integration on the uncertainty level in a supply chain using parameter based ordering policy is a one level increase in breach impact uncertainty when a breach of the type BP1 and BP2 occurs. There is no effect on uncertainty level when breach of the type BP1 occurs. At the operational level, the wholesaler is affected in a similar way to the supply chain but the retailer and manufacturer are unaffected by the full information sharing strategy under any of the breach profiles.

With the batch ordering system, adopting a full information sharing strategy does not affect uncertainty level when BP1and BP2 occurs but the uncertainty level is decreased by one level when PT occur. This means that a little increase in the RoC of the breach (comparing IBMS to PT) reduces the uncertainty level in a fully integrated mode by one level while a significantly high increase in RoC (comparing IBMS to AOW) has no effect. On the other hand, the uncertainty level is increased by a level when the more disruptive breach occurs. Interestingly, the impact uncertainty at the manufacturer is reduced by a level only under BP1, increased at

the wholesaler by a level only under BP3 and increased at the retailer by a level only under BP2.

RWM	SFDD			
	Retailer	Wholesaler	Manufacturer	SC Total
option I	0	0	0	0
option II	0	-1	0	-1
option III	0	0	0	0
	AOW			
	Retailer	Wholesaler	Manufacturer	SC Total
option I	0	-1	0	-1
option II	-1	0	0	0
option III	1	-1	0	0
	PT			
	Retailer	Wholesaler	Manufacturer	SC Total
option I	0	-1	0	-1
option II	0	0	1	1
option III	1	-1	0	0
	IBMS			
	Retailer	Wholesaler	Manufacturer	SC Total
option I	0	-1	0	-1
option II	0	0	1	0
option III	0	0	0	0

Table 6.11 Effect of WM mode on information security breach impact uncertainty level

Under the combined policy, RWM does not affect the uncertainty at the supply chain level under any of the breach profiles. At the operational level, the manufacturer is also unaffected by the full information sharing mode. However the retailer benefits with a level reduction in uncertainty only under increased RoC while the wholesaler experiences a level increase in uncertainty under similar conditions.

6.4.4 Summary and Cost Implication of Entropy Change Due to Information Sharing

The implication of the effect of various information sharing modes on uncertainty level to monitoring and review control cost is patterned in a similar way to that described for the structure effect in section 6.3.4. The result in Table 6.12 reveals the cost implication of engaging in information sharing at the RW, WM and RWM levels based on the monitoring and review level change required.

	Monitoring and Review Cost Implication		
Option I	RW	WM	RWM
SFDD	-	-	-
AOW	$-A_1$	-	$-A_1$
IBMS	$-I_1$	$-I_1$	$-I_1$
PT	-	-	$-P_1$
Extra Cost Saving	$\mathbf{-(A_1+I_1)}$	$\mathbf{-I_1}$	$\mathbf{-(A_1+P_1+I_1)}$
Option II	RW	WM	RWM
SFDD	$-S_1$	-	$-S_1$
AOW	-	-	-
IBMS	-	-	-
PT	-	-	P_1
Extra Cost Saving	$\mathbf{-S_1}$	-	$\mathbf{P_1-S_1}$
Option III	RW	WM	RWM
SFDD	-	-	-
AOW	A_1	-	-
IBMS	-	-	-
PT	P_1	P_1	-
Extra Cost Saving	$\mathbf{A_1+P_1}$	$\mathbf{P_1}$	-

Table 6.12 Cost implication of structural reconfiguration effect on monitoring and review cost

Under the parameter based ordering, it is clear from the result that there is additional cost required by the supply chain, where retailer's information is being shared with the wholesaler, in order to increase its control over AOW and IBMS information security breach impact. Including the manufacturer in the sharing of retailer information increases the monitoring and review cost by P_1. Information sharing that does not involve sharing retailer's information but that only focuses on sharing wholesaler information with the manufacturer needs to increase its monitoring level for IBMS and hence will incur additional cost of monitoring and review. Therefore with the RW and RWM strategy, total monitoring and review control cost should increase if the same level of control over security breach impact as that of a non-integrated supply chain is to be maintained.

With the batch ordering system, sharing retailer's information with the wholesaler alone requires an increase in total monitoring and review cost by S_1 while including the manufacturer in this information sharing reduces the S_1 cost by providing additional cost saving of P_1. The strategy that only involves sharing wholesaler's information with the manufacturer does not incur any additional cost regardless of the breach profile.

Information sharing under the combined batch-and-parameter based ordering policy does not increase the uncertainty or complexity of the supply chain. The result suggest that sharing retailer's information with the wholesaler alone saves monitoring and review cost (by A_1+P_1) while extending this information to the manufacturer will only eliminate this benefit but it would still be at the same level with that of a non-integrated supply chain. On the other hand, only sharing wholesaler's information with the manufacturer helps save monitoring and review cost by P_1.

6.4.5 Decision Framework for Supply Chain Information Sharing Level

Again the final decision of which ISL is most desirable for each ordering policy should not only be based on the above assessment, as it might be misleading, but also on the entropy assessment and its implication. Similar to the discussion in section 6.3.5, this section evaluates the performance of each ISL under various information security breach at the supply chain level. The decision framework incorporates the direct mitigation cost benefit of engaging in information sharing at different levels and the cost associated with uncertainty level change due to security breach. To decide on the ideal level of information sharing for each ordering policy, the steps outlined in section 6.3.5 is applied but with information sharing level as focus instead of supply chain structure. The result of this computation is summarised in Table 6.13. Recall that 1% is equivalent to £3.97 (for option I); £3.10 (for option II); £3.00 (for option III).

From the result in Table 6.13, it is clear that under a parameter based ordering system, the supply chain will have to incur certain costs to increase the level of control that may otherwise be lost after adopting information sharing strategies. Based on simple logic, the best information strategy is this case would depend on the following conditions. If P_1 is lesser than 30%, then RWM is the best choice, otherwise RW will be the best choice. However if A_1 is less than 35%, then WM would become the ideal and if I_1 is less than 1%, then a non-integrated scenario would be the ideal case.

Option I	RW	WM	RWM
Aggregate benefit (n-BS and BS)	36%	1%	66%
Monitoring and review cost	-(A_1 +I_1)	-I_1	-(A_1+P_1+I_1)
Overall benefit	36% - (A_1 +I_1)	1% -I_1	66% - (A_1+P_1+I_1)
Decider	Max (RW, WM, RWM)		
Final Decision	RWM (IF P_1<30%, Else RW (IF A_1< 35%, Else WM (IF I_1<1%, Else No integration)))		
Option II	RW	WM	RWM
Mitigation benefit	12%	6%	31%
Monitoring cost	-S_1	-	P_1-S_1
Overall benefit	12%-S_1	6%	31% + P_1-S_1
Decider	Max (RW, WM, RWM)		
Final Decision	RWM (IF S_1 < P_1 + 25%, Else WM)		
Option III	RW	WM	RWM
Mitigation benefit	18%	27%	32%
Monitoring cost	A_1+P_1	P_1	-
Overall benefit	18% + A_1+P_1	27% + P_1	32%
Decider	Max (RW, WM, RWM)		
Final Decision	RWM (IF P_1<5%, Else WM (IF A_1> 9%, Else RW))		

1% is equivalent to £3.97 (for option I); £3.10 (for option II); £3.00 (for option III).

Table 6.13 Decision framework for ISL adoption under each ordering policy

For a batch ordering system, the decision is clearly between RWM and WM. If the cost magnitude of S_1 is less than that of P_1 + 25%, then the full integration mode would be the ideal choice for the batch ordering system under these conditions, otherwise WM would be the preferred choice.

With the combined policy, the decision is a bit more complicated than in the batch ordering system. The selection would be RWM, provided the magnitude of P_1 is less than 5%, otherwise WM would be favoured. However, if A_1 is less than 9%, RW becomes the best choice.

6.5 INFLUENCE OF THE INTERACTION BETWEEN ISL AND STRUCTURE ON UNCERTAINTY LEVEL OF BREACH IMPACT

The influence of structural reconfiguration and information sharing strategies has been discussed separately in section 6.3 and 6.4 respectively. However the aim of this section is to establish how combining the two strategies would affect breach impact uncertainty and the cost implication of this under the three ordering policies. Given the proposed indirect cost assessment (entropy assessment), the objective is to know if combining both improvement strategies would be beneficial to the supply chain cost performance or if using a single improvement strategy would be better. It is also aimed to establish whether the decision made from direct cost assessment alone will be different from that made when the indirect cost assessment has been included. The result of the entropy level rating of the various combination of information sharing level (ISL) and supply chain structure scenarios can be found in Appendix 6.3.

6.5.1 Summary and Cost Implication of Entropy Change Due to the Combined Effect of Information Sharing and Supply Chain Structure

The change in entropy level as a result of the combined effect is shown in Table 6.14 and the cost implication is shown in Table 6.15. As a general observation from Table 6.14, under the parameter based policy, the effect of information sharing on the breach impact uncertainty level in different supply chain structures is mostly negative when the breach is of the BP1 type. The interaction effect is mostly of the stabilising or improvement type on uncertainty level under BP3 while it is mostly of a stabilising type under BP2. With the batch ordering policy, the interaction effect is mostly of the stabilising type under all three breach profiles. For the combined policy type, the interaction effect is predominantly of the stabilising type under BP1 type while the effect is predominantly of the improvement type under BP2 and BP3.

Of the three ordering options, it appears that the batch ordering policy is the most stable to uncertainty level change due to the interaction effect under all three breach profiles. The combined policy offers the next best stability but the inherent instability favours the interaction effect under breaches of the type BP2 and BP3. The parameter based policy is the most unstable of the three to the interaction effect and this instability does not favour the interaction effect under breaches of type BP1.

In terms of the implication to cost, the result in Table 6.15 reveal that the interaction effect between the structural reconfiguration and information sharing strategies in a batch ordering system hardly incur additional monitoring and review cost, but the combined batch-and-parameter ordering policy provide additional cost saving in all but one of the various combinations. The interaction effect in a parameter based policy supply chain, however, requires additional monitoring and review cost for virtually all the combination scenarios.

	RW			WM			RWM		
	Option I								
Breach	WH	MF	NT	WH	MF	NT	WH	MF	NT
SFDD	0	1	0	1	0	1	1	1	0
AOW	0	0	0	-1	-1	0	0	0	0
PT	-1	0	-1	0	-1	-1	-1	-1	-1
IBMS	-1	-1	-1	-1	-1	-1	-1	-1	-1
	Option II								
	WH	MF	NT	WH	MF	NT	WH	MF	NT
SFDD	0	0	-1	0	0	0	0	0	0
AOW	0	0	0	0	0	0	1	0	1
PT	0	0	0	0	0	0	0	0	0
IBMS	0	0	0	0	0	0	0	0	0
	Option III								
	WH	MF	NT	WH	MF	NT	WH	MF	NT
SFDD	1	1	1	0	0	1	1	1	1
AOW	1	0	1	1	0	1	1	1	1
PT	0	0	0	1	0	0	0	0	0
IBMS	0	0	0	0	0	0	0	0	0

Table 6.14 Relative change in uncertainty level due to ISL and structure interaction effect

	RW			WM			RWM		
	Option I								
Breach	WH	MF	NT	WH	MF	NT	WH	MF	NT
SFDD	-	S_1	-	S_1	-	S_1	S_1	S_1	-
AOW	-	-	-	A_1-	A_1-	-	-	-	-
PT	P_1-	-	P_1-	-	P_1-	P_1-	P_1-	P_1-	P_1-
IBMS	I_1-	I_1-	I_1-	I_1-	I_1-	I_1-	I_1-	I_1-	I_1-
Extra Cost Saving	$-(P_1+I_1)$	$-I_1$	$-(P_1+I_1)$	$S_1-A_1-I_1$	$-(A_1+P_1+I_1)$	$S_1-P_1-I_1$	$S_1-P_1-I_1$	$S_1-P_1-I_1$	$-(P_1+I_1)$
	Option II								
	WH	MF	NT	WH	MF	NT	WH	MF	NT
SFDD	-	-	S_1-	-	-	-	-	-	-
AOW	-	-	-	-	-	-	A_1	-	A_1
PT	-	-	-	-	-	-	-	-	-
IBMS	-	-	-	-	-	-	-	-	-
Extra Cost Saving	-	-	$-S_1$	-	-	-	A_1	-	A_1
	Option III								
	WH	MF	NT	WH	MF	NT	WH	MF	NT
SFDD	S_1	S_1	S_1	-	-	S_1	S_1	S_1	S_1
AOW	A_1	-	A_1	A_1-	-	A_1	A_1	A_1	A_1
PT	-	-	-	P_1	-	-	-	-	-
IBMS	-	-	-	-	-	-	-	-	-
Extra Cost Saving	S_1+A_1	S_1	S_1+A_1	A_1+P_1	-	S_1+A_1	S_1+A_1	S_1+A_1	S_1+A_1

Table 6.15 Cost implication of the interaction effect on monitoring and review cost

6.5.2 Decision Framework for Combining Information Sharing and Supply Chain Structure

To decide on the ideal combination of information sharing level and structure for each ordering policy, the decision framework incorporates the direct impact assessment and the indirect impact assessment. Again, the steps outlined in section 6.3.5 are followed. The result of the computation in step (iii) has been established in section 5.5 and this is added to the cost implication of uncertainty level change already established in section 6.5.1. The overall benefit is computed and shown in Table 6.16. Recall that 1% is equivalent to £3.97 (for option I); £3.10 (for option II); £3.00 (for option III).

	RW		
	WH	MF	NT
Option I	46.3% -(P_1+I_1)	45.5% -I_1	8.2% -(P_1+I_1)
Option II	52.9%	63.6%	23.1% - S_1
Option III	43.9% + S_1+A_1	53% + S_1	2.7% + S_1+A_1
	WM		
	WH	MF	NT
Option I	4.2% +$S_1-A_1-I_1$	- $(1.2\% +A_1+P_1+I_1)$	$S_1-P_1-I_1$-2.9%
Option II	57.5%	40.3%	51.5%
Option III	67% + A_1+P_1	39.8%	54.1% + S_1+A_1
	RWM		
	WH	MF	NT
Option I	$S_1-P_1-I_1$+87.4%	$S_1-P_1-I_1$+88.4%	44.4% - (P_1+I_1)
Option II	75% + A_1	78.3%	34.1% + A_1
Option III	59.7% + S_1+A_1	61.3% + S_1+A_1	34.0% + S_1+A_1

1% is equivalent to £3.97 (for option I); £3.10 (for option II); £3.00 (for option III).

Table 6.16 Overall Mitigation Benefit under combined strategies

It is clear from the result that given a batch ordering or combined batch-and-parameter based ordering system, significant benefit can be derived when the retailer shares its inventory information (including market demand) and even greater benefit can be derived when this information is shared with the manufacturer. Interestingly, sharing only the wholesaler information with the manufacturer under similar ordering policies yields significant overall benefit to the supply chain, even more than the RW and RWM strategies in some instances. The benefit derived under a parameter based policy however depends on certain conditions.

It is important for supply chains to know, given their pre-existing conditions, how these two advocated performance improvement strategies can be adopted. For those pre-existing in certain structures similar to those described in this study, the best information sharing strategy would be desired. On the other hand, for those who have already adopted some form of information sharing strategy and would like to improve the structure of the supply chain would consider the best structural reconfiguration strategy. This decision, given pre-existing conditions, is explained in the subsequent sections.

6.5.2.1 Decision for structural reconfiguration given ISL and ordering Policy

The best combination of structural reconfiguration with existing information sharing strategy is shown in Table 6.17. For the parameter based ordering policy, decision of whether to adopt any reconfiguration strategy at all depends on the magnitude of P_1 and I_1. For a supply chain already adopting RW information strategy, if the magnitude of P_1 and I_1 is greater than 46.3% (which is equivalent to £ 183.8), then the supply chain is best to avoid adopting any of the reconfiguration strategies. Otherwise manufacturing or wholesaling simplification can be selected depending on whether P_1 is greater than 0.8% (equivalent to £3.2) or not. The decision for structural reconfiguration in supply chain with pre-existing WM and RWM strategies is predicated on certain conditions as well.

With the batch ordering and combined policy, the result in Table 6.17 suggests that structural reconfiguration can be implemented with potential for significant benefit. The decision of which reconfiguration strategy to select is quite straight forward in batch ordering system while in a combined policy type, the decision is not straight forward at least for the partial information sharing strategies (RW and WM).

	Option I	Option II	Option III
RW	MF (IF P_1>0.8%, Else WH (IF P_1+I_1<46.3%, Else No combination)	MF	MF (IF A_1< 9.1%, Else WH)
WM	WH (IF A_1< P_1+7.1%, Else NT (IF S_1>P_1+I_1+2.9%, Else No combination)	WH	WH (IF S_1<P_1+12.9%, Else NT)
RWM	MF (IF P_1+I_1 < 44.4%, Else No combination)	MF	MF

1% is equivalent to £3.97 (for option I); £3.10 (for option II); £3.00 (for option III).

Table 6.17 Structural reconfiguration strategy decision given various ISL

6.5.2.2 Decision for ISL Given Structure and Ordering Policy

The best combination of structural reconfiguration with existing information sharing strategy is shown in Table 6.18. With the parameter based policy, again, the decision to adopt any information sharing should be preceded by the examination of certain conditions and these conditions vary for different supply chain structures. Under the batch ordering system, the decision of which information sharing best suit the current structure is quite straight forward for all pre-existing structures, except for the network structure where the decision is between RWM and WM depending on the magnitude of A_1. For the combined policy type, the decision is also straight forward except under a wholesaler type structure (WH) where the decision is between RWM and WM depending on the size of S_1 and P_1.

	Option I	Option II	Option III
WH	RWM (IF P_1< 83.2%+A_1, Else WM (IF S_1 > 4.2% +A_1+I_1, Else No combination)	RWM	RWM (IF S_1 > 7.3% + P_1, Else WM)
MF	RWM (IF P_1< S_1 + 42.9%, Else RW (IF I_1<45.5%, Else No combination)	RWM	RWM
NT	RWM (IF S_1< 47.3%, Else WM (IF S_1>P_1+I_1-2.9%, Else No combination)	RWM (IF A_1>17.4%, Else WM)	WM

1% is equivalent to £3.97 (for option I); £3.10 (for option II); £3.00 (for option III).

Table 6.18 Information sharing level strategy decision given various supply structures

6.5.2.3 Decision for combining ISL and structural reconfiguration strategy given specific ordering policy

Supply chains seeking to improve their cost performance by adopting both improvement strategies, given a prevailing ordering policy, will need to decide

which combination of structural reconfiguration strategy and information sharing strategy would be most ideal. The best combination of structural reconfiguration with information sharing strategy under each ordering policy is shown in Table 6.19. The decision based on the direct cost assessment in the previous chapter (section 5.6) was RWM+MF for option I and option II and WM+WH for option III. However from the entropy assessment, this study has shown that such decisions based on direct cost assessment alone may, in fact, be misleading.

	Best Combination
Option I	**RWM+MF**(IF P_1< 92.6%+A_1, Else **WM+WH** (IF A_1< S_1- 41.3%, Else **RW+MF** (IF I_1<45.5%, Else **No combined adoption**)))
Option II	**RWM+MF** (IF A_1 <3.3%, Else **RWM+WH**)
Option III	**RWM+MF** (IF S_1> 5.7% + P_1, Else **WM+WH**)

1% is equivalent to £3.97 (for option I); £3.10 (for option II); £3.00 (for option III).

Table 6.19 Decision making for combined ISL and structural reconfiguration strategy

6.5.2.3 Decision for the overall best ISL, Structure and Ordering Policy Combination

Through the process of elimination by pairwise comparison one can obtain the scenario that offers the best combination of ISL, supply chain structure and ordering policy. It is inaccurate to use the percentage values for direct comparison between all scenarios because the magnitude of a percentage is different for each ordering policy. Therefore an accurate and direct comparison would require the use of cost (£) instead of percentage. It has been established that 1% is equivalent to £3.97 (for option I); £3.10 (for option II); £3.00 (for option III).

By considering the best options for each ordering policy and substituting the percentage values with their corresponding pound (£) equivalent, the overall best combination is selected contingent on the following conditions:

RWM+WH+II (IF P_1<£31.5, Else WM+WH+III (IF S_1<£7.1+P_1, Else RWM+MF+III (IF A_1>£167.05-P_1-I_1, Else RWM+MF+I (IF S_1>P_1+I_1- £108.22, Else RWM+MF+II))))).

The decision could be any of the above five combinations depending on the magnitude of S_1, A_1, P_1 and I_1 which are the respective average daily cost of

increasing the monitoring and review activities by one level for SFDD, AOW, PT and IBMS breaches respectively.

6.6 CONCLUSION

Recall that this study is about understanding the impact of information security breach with the presumption that this cost estimate is in itself uncertain. The study has shown that predicting this impact can be uncertain and judging only by the average cost estimate may be misleading. Many organisations do not consider breaches with low cost impact as worthy of concern but history has shown that what might seem benign a year ago may become the bane of existence the following year due to changing complexities or environmental conditions. It is therefore imperative to understand the uncertainty surrounding the cost estimate so that an organisation would not be caught unawares. After the 2011 Sony's PlayStation Network (PSN) security breach incidence, some experts opined that Sony was not prepared for such an attack and did not respond to the breach adequately and did not warn their consumers soon enough (Newman, 2011, Pollack, 2011). One may therefore presume that had Sony been certain about the huge impact of hacking incidence in their risk assessment then it might have implemented the right mix of risk prevention and mitigation strategies or at least increased their level of monitoring and review control (i.e. correction strategy). This study has therefore proposed measuring this uncertainty using entropy assessment.

From the entropy assessment, the study found that the impact of information security breach on supply chains operating with an optimal batch ordering policy is more stable, hence less control is required when changing strategic elements of the supply chain than in a supply chain using the combined policy type. Those with the parameter based ordering system would require additional level of control when confronting the impact of information security breach.

The study also found that the effect of the strategic factors on the uncertainty level is similar for the batch policy and the combined policy type when the profile of the breach is of the less disruptive and less recurring nature (BP1) or highly disruptive but less recurring (BP3). However, when the profile of the breach is highly increased in terms of the breach recurrence rate (as in BP2), this effect is dissimilar with the

combined policy parameter enjoying better stability and hence offering better control.

In terms of the cost implication of uncertainty level change, the results suggest that the interaction effect between the structural reconfiguration and information sharing strategies in a batch ordering system hardly incur any additional monitoring and review cost, but the combined batch-and-parameter ordering policy provide additional cost saving in virtually all the various combinations. On the other hand, the interaction effect in a parameter based policy requires additional monitoring and review cost in the supply chain for virtually all scenarios.

This study has shown that the decision to undertake restructuring given an ISL or the decision to engage in information sharing given a particular structure is not straight forward from the initial impact cost assessment. Hence the conditions for decision has been shown in the framework for deciding ISL or supply chain structure for each ordering policy and for deciding ordering policy for each ISL and Structure combinations. The overall best supply chain state (i.e. ISL+ Structure+ Ordering option) has been shown and this depends on the magnitude of the cost implications of the various information security breaches. In conclusion, upon impact uncertainty consideration using entropy assessment, the study has shown that the cost associated with the impact uncertainty could make, what was otherwise thought of as a good decision into a wrong one.

Chapter 7 : IMPLICATION AND CONCLUSION OF FINDINGS

Information security breach is increasingly becoming a huge subject in supply chain management owing to the increased level of dependence on information systems and the increased level of interdependence between operating partners brought about by integrated information systems. Several threats to information security exist that can compromise the confidentiality, integrity and availability of the goods and/or services provided by organisations. Therefore information security breach impact assessment is strongly advocated for a compromise to the information system may have restrictions on the flow of information, which may ultimately disrupt the flow of material in the supply chain. This has been shown to have catastrophic impact on the cost performance as well as the service performance of supply chain agents.

To understand the landscape of information security impact and the role certain supply chain strategic factors play in this impact, this research was divided into three separate studies. The first study (Chapter 4) was to understand the improvements in supply chain performance that can be derived, under normal circumstances (i.e. no information security breach), when those strategic factors are changed from one alternative to another. This also serves as the bench mark for estimating the impact of information security breach. The second study (Chapter 5) examined the impact of information security breach on supply chain performance and how each of these strategic factors fare in the face of these breaches. The third study (Chapter 6) established the uncertainty associated with the impact of each security breach using entropy theory and the implication of this to the monitoring and review level required in the supply chain. This represented an indirect cost impact assessment which was used in a final decision framework to guide improvement strategy adoption decisions.

In the following sections, the main research findings of three studies will be summarized respectively and the managerial implications of the findings will then be discussed. It is followed with the research contributions. Finally, a critical discussion of limitations is provided before the future research directions are pointed out.

7.1 RESEARCH FINDNGS AND MANAGERIAL IMPLICATION OF STUDY 1

7.1.1 The Role of Ordering Policy in a Non-Breach Scenario

7.1.1.1 Effect on Ordering Pattern

Given similar operating conditions, the magnitude of the order quantity each time an order is placed is higher in a batch ordering policy than in a parameter based ordering policy. Consequently, the frequency of ordering in the former is less than that of the latter. The cost performance of the batch ordering system was better than that of the parameter based ordering suggesting that the ordering pattern (magnitude of order quantity and the frequency of ordering) of the former was more favourable to supply performance than the latter. However, the ordering pattern of an ordering policy which combines aspects of the batch ordering system and parameter based ordering was the median of the three and the performance under this combined policy was the highest of all three ordering policies. This indicates that there exists a point along the ordering pattern continuum between batch ordering and parameter based ordering where performance is optimal (or at least near optimal). Therefore the combined policy appears to be an improvement of the batch ordering and the parameter based ordering and can be considered to be an ordering policy improvement strategy. The same result was observed under all three supply structures which validates the findings.

Managerial Implication: Certain supply chains favour certain shipping strategies depending on whether bulk purchase is made less frequently or whether smaller quantities are needed to be shipped more frequently. The optimal EOQ ordering type would require a shipping strategy that favours higher order quantity with less ordering frequency while a base stock policy under the same supply chain condition would require a shipping strategy that favours lower order quantities ordered more frequently.

7.1.1.2 Effect on Bullwhip

The bullwhip effect has been the subject of many articles on supply chain management. Several authors have examined the factors that contribute to an increase in the bullwhip effect while others have suggested improvement strategies. However this study supports the earlier contribution of Chen and Samroengraja

(2004) and has shown that incorporating strategies to reduce the bullwhip effect does not necessarily constitute improvement in supply chain cost performance. In fact, as the results suggest, the policy with the lowest bullwhip effect (option I- parameter based ordering policy) has higher supply chain cost than that with higher bullwhip effect (option II- batch ordering policy). This study also included the wholesaler tier in the simulation modelling, which was not included in the work of Chen and Samroengraja (2004) when they made that assertion, and found evidence to support the claim of Baganha and Cohen (1998) that the wholesaler has a stabilising effect on bullwhip effect. However this claim of the stabilising role of the wholesaler **does not always apply**, at least, to the combined batch-and-parameter based policy type (option III).

Managerial Implication: The implication of the bullwhip effect from past literature is that upstream agents tend to carry excess inventory and therefore incur higher inventory holding cost. Part of the strategies of reducing the bullwhip effect could be introducing a wholesaler which could effectively be a sort of distribution center acting autonomously. Again this has to be justified by analysing the cost of having such a structure against the reduction in inventory and other associated costs that it will generate.

7.1.2 The Role of Structural Reconfiguration in a Non-Breach Scenario

7.1.2.1 Effect on Ordering Pattern

Structural reconfiguration as a strategy does not affect the ordering pattern of a parameter based policy but affects that of batch and combined batch-and-parameter based ordering by reducing the effective average order quantity (EAOQ) and a commensurate increase in ordering rate (OR). Consequently, the cost performance in a parameter based ordering system does not change while the cost performance in the other two ordering policies is improved by any of the three structural reconfiguration strategies considered. It is clear that simplifying the ‘deliver’ aspect of the supply chain (i.e. the wholesaler tier) is the best option for a combined policy type while simplifying the ‘make’ aspect (i.e. the manufacturer tier) is the best choice of structural reconfiguration for a supply chain using a batch ordering policy.

Managerial implication: Therefore one can infer that supply chains using the parameter based policy (base stock policy) need not change their shipping strategy

when considering structural reconfiguration, but those using batch or combined batch-and-parameter based models should revisit their shipping strategy to adopt one that favours lesser order quantity placed more frequently. In addition, changing the structure of a supply chain can be difficult especially for those organisations in existing serial structures. For a supply chain using batch ordering policy (e.g. optimal EOQ model) who wants to derive the benefit of structural reconfiguration but does not want to go through the hassle of restructuring should consider only modifying its policy to the combined batch-and-parameter based policy to reap similar benefits. Therefore the combined policy can be used as a supply chain performance improvement strategy.

7.1.2.2 Effect on Cost Performance

This study has shown that, like all improvement strategies, structural reconfiguration does not benefit all the parties in the supply chain and incentives need to be given to participating agents who are not benefiting from it. Hence a decision framework for accepting a given improvement strategy is developed and shown in Figure 4.1.

Managerial Implication: For the parameter based policies such as the base stock policy, again neither simplification nor networking strategies offer any significant benefit to the supply chain, hence adopting either of these strategies is basically futile. For batch ordering policies such as the optimal EOQ model, the better strategy would be to share the orders between agents of the same tier rather than simplify the supply chain at either the wholesaler or the manufacture tiers, although the latter strategy still holds benefit. With the combined policy type such as the modified base stock policy with EOQ component, the preferred strategy is the simplification strategy at the wholesaler tier rather than networking strategy.

7.1.3 The Role of Information Sharing Level in a Non-Breach Scenario

7.1.3.1 Effect on Ordering Pattern

The general effect of information sharing on the ordering pattern of the supply chain agents using the shared information is an increase in the effective average order quantity (EAOQ) and a commensurate increase in ordering rate (OR). This is contrary to the effect of structural reconfiguration where the case is the other way round. The ordering pattern of all supply agents using the parameter based policy is not perturbed by any of the information sharing strategies but under the other two

policies, only the retailer's ordering pattern is not affected by all three information sharing modes.

Managerial Implication: Therefore, under the batch or combined batch-and-parameter based models, users of downstream inventory information should revisit their shipping strategy to adopt one that favours more order quantity placed less frequently while supply chains using the parameter based policy (base stock policy) need not change their shipping strategy when considering information sharing at any level.

7.1.3.2 Effect on Bullwhip

From the control theory perspective, engaging in information sharing does not change the nature of bullwhip effect for options I and II but only changes the magnitude. The stabilising effect of the wholesaler is more pronounced when the wholesaler using a batch ordering policy (e.g. optimal EOQ model) or a combined batch-and-parameter based ordering (e.g. modified base stock policy) is privy to, and uses, actual demand information.

Managerial Implication: The supply chain would be able to reduce the bullwhip effect even further when a wholesaler type entity is introduced and retailer's information is shared with at least the wholesaler.

7.1.3.3 Effect on Cost Performance

At the supply chain level, a supply chain using parameter based policy such as the base stock policy only benefits from information sharing when the wholesaler and/or the manufacturer uses retailer's inventory information (which includes the market demand information). However the supply chain obtains benefit regardless of the mode of information sharing (RW, WM or RWM) under a batch or combined batch-and-parameter based ordering policy. Interestingly, RW and RWM favours the parameter based ordering policy more than the other two policies while WM mode favours the combined policy more.

Managerial Implication: The partial information sharing strategy that involves sharing retailer's inventory information (RW) can be adopted in parameter based and batch ordering systems without any consideration for giving incentives to non-benefiting members. However, in the combined policy type system, such information sharing strategy can still be adopted but the responsibility of incentive giving lies

with the manufacturer. On the other hand, the partial information sharing strategy that does not involve sharing retailer's information but instead involves sharing wholesaler information with the manufacturer (WM) is not likely to be acceptable by the retailer and wholesaler. This is because the overall benefit of the strategy is not large enough to incentivise both the retailer and wholesaler in a parameter based system while the manufacturer would have to incentivise both downstream agents under the batch and combined batch-and-parameter systems for such strategy to be acceptable. The full information sharing mode (also referred to as full integration in this study) is completely acceptable by all supply chain agents and no incentivisation is required under parameter based and batch ordering policies respectively. However, under the combined policy, the retailer and wholesaler are less inclined to adopt RWM strategy unless the manufacturer can provide certain incentives to justify their involvement.

7.1.4 The Combined Role of Information Sharing and Structural Reconfiguration in a Non-Breach Scenario

This study has shown that the best improvement strategy under the information sharing category and that under the structural reconfiguration strategy category does not necessarily have the best synergy performance. Hence, the decision to adopt one single strategy should be made with a long term view (i.e. strategic) that includes the possibility of adopting another improvement strategy from a different improvement category, even if the other improvement strategy would be considered much later in the future.

Managerial Implication: Therefore the supply chain using the parameter based policy such as the base stock policy will do well to adopt full information sharing and manufacturing simplification strategies even if a stepwise adoption is considered. Clearly for the batch ordering policy such as the optimal EOQ model, although the individual best performance comes under networking and full integration separately, the best option on the long run would be the combination of manufacturing simplification and full integration strategies. Under the combined policy mode, the decision would be to adopt both wholesaling simplification and information sharing between the wholesaler and the manufacturer only as opposed to the full information sharing strategy.

7.2 RESEARCH FINDNGS AND MANAGERIAL IMPLICATION OF STUDY 2

The second study has shown that the magnitude and direction of breach impact would depend on the breach profile, and the type of ordering policy being used in the supply chain. However the magnitude would depend on the current structure and information sharing level in the supply chain. On another level, this study has demonstrated that the impact of information security breach, however, can be mitigated by improvement strategies such as supply reconfiguration and information sharing as shown in this study. The impact of security breach is significant enough to affect supply chain decisions with regards to information sharing level (ISL) choice or supply chain structure preference and it has been established that the decision to opt for certain ISL and structure combinations should not be taken without disruption impact considerations.

7.2.1 The Role of Ordering Policy in a Breach Scenario

7.2.1.1 Effect on Breach Impact Resilience

The parameter based policy is the most resilient to the negative impact of a breach, while the batch ordering policy is the least resilient with the combined policy having the median resilience. On the other hand, priorities of information security management can be known when the breach is profiled according to the average disruption duration and the average rate of occurrence rate. These priorities would differ based on the ordering policy of choice.

Managerial Implication: Therefore, for a parameter based ordering policy, increased RoC only increases the oddly positive effect of a breach on the performance while disruption duration increases the negative effect. Therefore supply chain priority for such parameter based ordering policy would be to focus on reducing the disruption duration of a breach, hence breach correction or mitigation would be a priority. The priority for a supply chain with batch ordering policy and that for a combined batch-and-parameter based ordering is also breach mitigation as disruption duration had a greater negative effect on breach cost impact than RoC.

7.2.1.2 The Reverberating Effect

The reverberating effect of the breach impact depends on the ordering policy of choice. The effect consistently increases under the parameter based policy while the

effect consistently decreases under the batch ordering policy. Under the combined policy the effect increases but the stabilising effect of the wholesaler makes it decrease as it gets to the manufacturer.

Managerial Implication: Therefore supply chains using the parameter based ordering should be more wary of information security breach occurring downstream in the supply chain than those using batch ordering policy. In a supply chain using the combined policy type, the wholesalers specifically should be wary of information security breach occurring downstream. This study therefore calls for better cooperation among supply partners and supports the claim that information security breach (ISB) incidence should be shared between supply chain partners. This is so that upstream parties can be made aware of the incidence of the breach early enough to find ways to eliminate or reduce the reverberating effect of such a breach.

7.2.2 The Role of Structural Reconfiguration in a Breach Scenario

7.2.2.1 Structural Reconfiguration as a Breach Impact Mitigation Strategy

This section examined the effect of changing the structure of a supply chain from a serial structure configuration to any of the three structural configurations discussed earlier. It evaluated the performance of these three structures relative to what would have been obtained in the serial counterpart. Since these three structures are forms of simplifying the supply chain by reducing the number of agents at the wholesaler tier (WH structure) or at the manufacturer tier (MF structure) or by simply risk pooling (NT structure), this study has shown that reconfiguration to these structure types can be a worthwhile strategy that can help the supply chain improve cost performance and also reduce the impact of information security breach. A single-strategy decision framework that incorporates breach impact assessment was developed and shown in Figure 5.2.

Managerial Implication: Structural reconfiguration by itself does not mitigate the impact information security breach has on supply chain performance for a parameter based policy but instead makes it worse. The only exception is the MF structure where benefit is derivable and the retailer needs to share ISB incidence and data with the wholesaler. Reconfiguration will prove beneficial to batch ordering systems and batch-and parameter based policy in a security breach scenario and there is no need

for ISB data sharing and incentivisation after a security breach. In general, information security management (ISM) priority would be to focus more on prevention and deterrence when any of the structural reconfiguration strategies is adopted.

7.2.3 The Role of Information Sharing Level in a Breach Scenario

The performance of a partially or fully integrated supply chain under information security breach is significantly better than the performance of a non-integrated supply chain under similar conditions. In general, the full integration mode (RWM) is the preferable sharing mode regardless of the type of ordering policy be it parameter based or batch ordering or the combination of both. However, the profile of the breach affects the performance of each information sharing strategy and some strategies fare better under certain profiles than others.

Managerial Implication: Apart from the normal incentivisation required in a non-breach scenario, the study suggest that additional incentivisation for the reverberating effect of the breach is required for the wholesaler when the sharing mode does not include sharing the retailer's information under a parameter based or combined parameter based ordering policy. However, under the batch ordering system, further incentivisation and ISB sharing can be prevented when the partial information sharing strategy of type RW includes the manufacturer in information sharing.

7.2.4 The Combined Role of Information Sharing and Structural Reconfiguration in a Breach Scenario

The supply chain stands to benefit from a significant improvement in performance when these two strategies are used as long as the use and adoption is well informed. The study has highlighted the best information strategy given a specific supply chain structure and also the best structural reconfiguration strategy given a specific information sharing level that may be pre-existing in the supply chain. It has been shown that certain strategies fare better alone while others that are otherwise detrimental may yet prove beneficial when combined with other strategies.

Managerial Implication: These two improvement strategies could be used as part of breach impact management strategy in addition to the ISM measures as they reduce

the impact information security breach would otherwise have on a normal serial supply chain without information sharing.

7.3 RESEARCH FINDNGS AND MANAGERIAL IMPLICATION OF STUDY 3

To decide on the ideal configuration for each ordering policy, first the benefit of the improvement strategy is assessed under a non-breach scenario (n-BS). Then the performance under various information security breaches is evaluated and the best improvement strategy is selected based on the aggregate performance in a non-breach and in various breach scenarios. This aggregate performance is considered to be the potential benefit held by such an improvement strategy.

However since the impact of information security breach is uncertain in itself, organisations ought to be wary of this uncertainty and should be intentional about reducing it. The more certain you are of a negative impact the more convinced you are that a risk management strategy is needed. However the less certain you are the less convinced you are on implementing any risk management action which could be unwise in the long run. According to a 2002 survey by Mitroff and Alpaslan (2003), proactive businesses existed for an average 16yrs more than their reactive counterpart. This is perhaps due to the fact that the reactive ones were not certain of experiencing negative impact and therefore were not proactive about putting proper mitigation strategy in place. It is therefore of the essence to increase the certainty level of breach impact so that the necessary corrections or implementation can be put in place to avoid unprecedented future impact. Increasing the certainty level requires regular monitoring of the breaches and regular review of the supply chain. This knowledge of uncertainty is important in the supply chain as according to Mitroff and Alpaslan (2003) in Altay and Ramirez (2010), 95 percent of Fortune 500 companies are unlikely to be able to manage a disruption that the company has not experienced before because they are ill-equipped. This could be the bane of existence for most supply partners.

Reducing the uncertainty level requires actions that are appropriate to the uncertainty level. These actions involve increasing the level of information required to manage the supply chain and information security management effectively and be categorised as monitoring and review control measures. Several monitoring and

review activities or measures exist and any organisation cannot implement all of it but implementation must be guided by the level of control required by the specific organisation or supply chain.

In addition to the above argument this study also found that, of the three ordering options, it appears that the batch ordering policy is the most stable to the interaction effect under all three breach profiles in terms of uncertainty level change. The combined policy offers the next best stability but the inherent instability favours the interaction effect under breaches of the type BP2 and BP3. The parameter based policy is the most unstable of the three to the interaction effect and this instability does not favour the interaction effect under breaches of type BP1.

Managerial Implication: In terms of the implication to cost, the interaction effect between the structural reconfiguration and information sharing strategies in a batch ordering system hardly incur additional monitoring and review cost, but the combined batch-and-parameter ordering policy provide additional cost saving in all but one of the various combinations. The interaction effect in a parameter based policy supply chain, however, requires additional monitoring and review cost for virtually all the combination scenarios.

The study has shown that, given a batch ordering or combined batch-and-parameter based ordering system, significant benefit can be derived when the retailer shares its inventory information (including market demand) and even greater benefit can be derived when this information is shared with the manufacturer. Interestingly, sharing only the wholesaler information with the manufacturer under similar ordering policies yields significant overall benefit to the supply chain, even more than the RW and RWM strategies in some instances. The benefit derived under a parameter based policy however depends on the magnitude of a level change in the daily average monitoring and review cost of the various breaches.

7.5 SUMMARY OF THE RESEARCH CONTRIBUTION

This study examined the impact of various information security breach types on different supply chain scenarios. An examination of this impact with a focus on the role that supply chain structure, information sharing level and ordering policy play, in either mitigating or exacerbating it, is of significance to theory and practice. Not

only that, the notion of uncertainty of breach impact makes some organisations wary of investing in Information System Security. This study therefore applied the concept of entropy in measuring this uncertainty to guide organisations on how much investment to make and where the investment is needed most (i.e. priority), if at all it is required. This study was extensive to a level that has not been done before in past literature and provided some valuable insight that has significant managerial implications.

7.5.1 Theoretical Contribution

Theoretically, this study has extended the contribution of a few authors in the distinct fields of Supply Chain Management and Information Security Management. In the field of Supply Chain Management, this study extends the works of Hosoda and Disney (2004) and Chen and Samroengraja (2004) on the effect of ordering policy; Lau et al. (2002 and 2004) and Wu and Cheng (2008) on the impact of information sharing; and Beamon and Chen (2001) on the performance analysis of co-joined supply chain structure on supply chain performance, by examining the synergic impact of the various combinations of these strategic factors. The study found that the combination of the various alternatives of each strategic factor have varying effect on supply chain performance and the best alternative of one factor may not provide the best benefit when combined with the best alternative of another factor. Hence a long term perspective should be adopted in these decisions. However, a step wise adoption can still be done provided the alternatives represent the best combination on the long run.

In the Information Security Management field, this study appears to represent the first (if not the only) study in literature that quantified information security breach impact on supply chain inventory cost performance using the disruption duration and frequency of breach occurrence information. This study also extends the work of Whitman (2003) by not only using the frequency of breach occurrence but also including disruption duration in profiling information security breaches.

7.5.2 Methodological Contribution

A major contribution of this study, in terms of methodology, is the novel application of Shannon's Entropy (Shannon 1948) to information security breach impact assessment. Improvement strategies, while enhancing the cost performance of the

organisation or supply chain, may increase the complexity of the operation and hence make the impact of disruptions even more uncertain. Therefore this study has shown that the cost benefit of such improvement strategies should be weighed against the level of uncertainty introduced into the system. It has been established that a change in the uncertainty level has cost implication and it is important to include this indirect cost assessment in supply chain strategy decision making. Hence a simulation-entropy assessment methodology has been developed and presented in this study to help assess the direct and indirect cost impact of information security breach which is useful in evaluating any improvement strategies. The proposed methodology creates a more inclusive approach to impact assessment than other existing ones that only concentrate on the direct impact such as Bellefeuille (2005). This can also be applied to the assessment of other types of threat to supply chain operations. It can also be used to evaluate any strategic decision aimed at improving supply chain performance. The single-strategy and a joint-strategy adoption decision framework developed can be used to guide supply chain management decisions. The joint-strategy framework can be used particularly for understanding the counter-intuitiveness of combining two or more strategic decisions.

7.5.3 Contribution to Practice

In the budding field of Supply Chain Response to Information Security, this thesis is one of the pioneering works to study the influence of various supply chain based strategic factors such as ordering policy, information sharing level and supply chain structure on the level of impact information security breach can have on supply chain performance. In addition, this study has established that synergic effect of these strategic factors can be used as an information security breach impact mitigation strategy. This of course should not, in any way, become a substitute for the implementation of proper security control measures. Their use would however provide additional benefit that may offset the installation and running cost of appropriate security controls.

This study also has implication to organisations or supply chains that are interested in selecting third party security provider or those requiring the services of third party database or application hosting. Using a third party operator (TPO) takes the responsibility of IT or IT security away from the organisation or supply chain. It is

therefore advisable for organizations to select TPOs based on their security performance profile as evidenced by their historical performance in providing adequate security. This requires an assessment of their past and current ability to prevent security breach from occurring and on how quickly they are able to correct and restore the functionality of the system after experiencing a compromise. This assessment can be carried out by profiling the security threats facing the TPO and this can be done by asking the TPO for information relating to the history of security breach incidence that has occurred in the past. The security profile of such operators can be classified as BP1, BP2 or BP3 as shown in this study and this can be used as a performance criterion in third party service provider selection. This study has shown that organisations or supply chains should be wary of third party service providers with history of higher disruption duration profile than those with higher breach recurrence rate profile. In addition, the level and type of information required in managing and controlling the system would differ based on the security profile of the third party operator. Those with high disruption duration profile would worry more about the extent of negative impact when a breach occurs and those with high breach recurrence rate would worry more about the impact being negative or positive.

7.6 LIMITATIONS OF RESEARCH

This study would be incomplete if some of the limitations of this study are not mentioned. Every study has its limitations and this study is without a fair share of such limitations. One of the main draw backs of this study is that the assessment of information security breach is only based on four breach types. In practice a lot more breach types exist and organisations need to make an assessment of all the breach types they are exposed to. Having said that, this study has allowed for certain level of generalisability by examining the effect of the breach profile under high and low states and any organisation can anticipate what the impact of any unconsidered breach would be as long as the profile is known.

The focus of this study was on the benefit derived from changing the strategic factors from one alternative to another and does not include a consideration of the cost required to make such a change. The study agrees that a cost benefit analysis which compares the cost of implementing improvement initiatives against the benefit that is derivable is crucial to any acceptance decision. However, the assumption that

changing the structure or the ordering policy does not carry huge costs, is not farfetched. On the other hand, information integration may require substantial capital but it has been established that computing models such as cloud computing makes this cost relatively small. Given the peculiarity of supply chains, still this study believes the onus of decision falls on the supply chain manager after a careful consideration of the cost of such improvement initiatives against the benefits established in this study.

Another drawback in this study was the assumption made when a breach occurs. It was assumed that a customer's order is not lost and hence the customer will wait for the system to be restored and then place his order. While this may not be the reality for some organisations in the fast moving goods (FMG) industry, it is still applicable in some specialised markets with highly customised product. It can even be argued that based on the work of Capraro et al. (2003) and Hennig-Thurau and Klee (1997) it is understood that loyal customers are still likely to purchase from vendors despite incessant dissatisfaction. In the same line, it was assumed that the demand during the disruption period is zero and this may affect the forecast estimate especially when the disruption duration is very high. While the author believes that such an assumption may affect the breach impact outcome, the effect will not be felt when the moving average is estimated over a very long period of time. In other words, as the number of periods increases, the effect of that assumption decreases.

While the ordering policies used may not be the optimal for each scenario, it is important to state that these policies are frequently used in practice. In addition, this study does not in any way claim that the forecasting technique used (i.e. Moving Average Technique) is optimal but it is quite frequently used in practice and commonly studied. Hence its use is somewhat justified.

The overarching issue of simulation studies is the question of fitness for purpose (Shannon 1998). Therefore despite some of the above listed limitations, which have been somewhat justified, the simulation model used in this study is fit for the purpose for which it was built. The supply chain has been modelled in a similar way to established supply chain operations and the input parameters used were adapted from established literature, Lau et al. (2002 and 2004). The output of the experiments were verified and validated. Although the simulation model assumptions may affect

the generalisability of the study, a sensitivity analysis of the models to increased demand variation shows that only the magnitude of the impact is affected, not the direction of the impact. Therefore the findings can be generalized to a reasonable extent.

7.7 FUTURE RESEARCH

There are various types and causes of information disruption (perturbation) that can occur in the supply chain/network. There is however a need for systematic classification of information threats and how these threats impact the entire network. Although some classification of threat exist emanating from surveys done by practitioners (Baker et al., 2010, Potter and Beard, 2012); institutions (Stoneburner et al., 2002, Richardson, (2009)) and; academic sources (Samy et al., 2010, Warren, 2000, Whitman, 2003, Loch et al., 1992, Kim et al., 2011), these are partial lists and there is need for a complete list of threats to information and how these impact the network and how the supply chain context can be leveraged to contain these impacts. It is therefore essential to have a systematic and in-depth investigation into the impact of Information Management on network operations and collaboration success. To set the ball rolling, this study has proposed a simulation-entropy assessment approach to investigate the impact of established threats to information flow on the performance of supply chain and how supply chain contextual factors moderate these impacts.

Using appropriate case studies or interviews, the cost-benefit analysis should be carried out for different supply chains in a future study to further substantiate the use of the approach discussed in this study.

The contextual factors referred to in this study are the structure of the supply chain, level of integration and ordering policy. These factors, among other complexity drivers, have more alternatives that require evaluation to build a more holistic picture of the role of context in supply chain studies.

The impact of assuming zero demand during the breach disruption period would be investigated under varying forecasting techniques. The forecasting technique generally requires an estimation of future demand based on the actual demand from past period. |However, the number of past period demand used in this estimation

may vary for different organisations and it is believed that this will affect the impact of information security breach when the demand during the disruption period is assumed to be zero. The future study should also investigate the effect of using other assumptions apart from the zero demand assumption during the disruption duration. An example is the presumption that demand during the disruption period is same as that of the last non-zero demand or that it is the average demand over a selected number of past periods.

APPENDIX 4.1 SIMULATION OUTPUT OF ALL THE EXPERIMENTED SCENARIOS

Average cost performance of all the scenarios for options I, II and III.

H-Holding Cost; B- Backlog cost; O- Ordering cost.

Option I													
	Retailer				Wholesaler				Manufacturer				SC
	H (£)	B (£)	O (£)	Total (£)	H (£)	B (£)	O (£)	Total (£)	H (£)	B (£)	O (£)	Total (£)	Total (£)
NI-S	0.0	140.0	54.8	194.9	1.9	56.0	54.8	112.7	24.7	5.1	59.6	89.4	397.0
NI-WH	0.0	144.1	54.9	199.0	0.5	59.6	52.4	112.4	21.9	3.0	59.7	84.7	396.1
NI-MF	0.0	139.8	54.9	194.8	1.8	55.3	54.9	112.0	21.8	3.0	54.7	79.5	386.3
NI-NT	0.0	144.0	54.9	198.9	0.5	59.5	54.9	114.9	21.9	3.1	59.7	84.8	398.6
RW-S	0.1	116.4	54.8	171.3	5.2	32.2	54.8	92.3	5.7	26.7	59.7	92.2	355.8
RW-WH	0.1	116.4	54.9	171.4	2.5	31.8	52.4	86.7	3.5	26.6	59.8	89.9	348.1
RW-MF	0.1	116.3	54.9	171.2	4.8	31.6	54.9	91.3	3.5	26.4	54.8	84.8	347.4
RW-NT	0.0	129.3	54.9	184.2	6.5	44.7	54.9	106.1	3.6	26.6	59.8	90.1	380.4
WM-S	0.0	143.9	54.8	198.7	1.7	59.8	54.8	116.2	8.2	9.6	59.8	77.5	392.5
WM-WH	0.0	145.6	54.9	200.6	0.4	61.1	52.4	113.9	9.1	4.7	59.9	73.7	388.2
WM-MF	0.0	145.3	54.9	200.2	1.6	60.7	54.9	117.1	4.5	9.3	54.9	68.7	386.0
WM-NT	0.0	147.1	54.9	202.1	0.5	62.6	54.9	118.0	6.3	6.5	59.9	72.7	392.7
RWM-S	0.1	100.7	54.8	155.6	7.7	16.3	54.8	78.8	17.7	2.2	59.8	79.6	314.0
RWM-WH	0.1	98.2	54.9	153.2	4.6	13.4	52.4	70.4	19.2	1.0	59.9	80.0	303.6
RWM-MF	0.1	100.9	54.9	155.9	7.5	16.0	54.9	78.5	13.2	1.5	54.9	69.6	304.0
RWM-NT	0.0	114.4	54.9	169.3	9.5	29.7	54.9	94.1	15.4	1.1	59.9	76.3	339.8

Option II													
	Retailer				Wholesaler				Manufacturer				**SC**
	H (£)	B (£)	O (£)	Total (£)	H (£)	B (£)	O (£)	Total (£)	H (£)	B (£)	O (£)	Total (£)	**Total (£)**
NI-S	2.4	63.3	54.2	120.0	17.0	16.9	52.9	86.8	39.2	9.1	54.7	103.0	**309.8**
NI-WH	2.1	67.2	54.4	123.7	9.4	18.8	51.6	79.8	34.7	6.3	54.7	95.6	**299.2**
NI-MF	2.1	66.8	54.4	123.4	15.7	18.3	53.0	87.1	30.5	7.0	52.3	89.8	**300.3**
NI-NT	1.8	68.5	54.4	124.7	8.9	20.6	53.4	82.8	28.1	7.3	54.7	90.1	**297.6**
RW-S	2.7	56.9	54.2	113.8	20.9	9.8	52.3	83.0	46.2	4.3	54.7	105.3	**302.1**
RW-WH	2.7	56.7	54.4	113.8	20.2	7.1	51.1	78.5	49.2	4.6	54.8	108.6	**300.8**
RW-MF	2.5	58.5	54.4	115.4	21.1	9.3	52.4	82.9	37.3	4.4	52.3	94.0	**292.3**
RW-NT	1.6	71.6	54.4	127.6	23.2	24.2	52.4	99.8	34.9	4.8	54.8	94.5	**321.9**
WM-S	2.3	65.2	54.2	121.8	15.6	18.9	52.9	87.5	25.9	15.6	53.7	95.3	**304.5**
WM-WH	2.1	67.6	54.4	124.0	8.8	19.3	51.6	79.7	29.5	8.7	53.8	92.1	**295.8**
WM-MF	2.0	70.9	54.4	127.3	14.0	22.7	53.0	89.7	19.7	17.2	51.9	88.7	**305.7**
WM-NT	1.8	69.7	54.4	125.9	8.2	22.0	53.4	83.5	24.7	11.1	53.8	89.5	**298.9**
RWM-S	2.7	57.3	54.2	114.2	19.2	10.3	52.3	81.8	25.4	10.5	55.3	91.3	**287.3**
RWM-WH	2.7	56.9	54.4	113.9	17.7	7.3	51.1	76.2	23.3	13.0	55.4	91.8	**281.9**
RWM-MF	2.4	59.5	54.4	116.3	19.1	10.5	52.4	82.0	17.7	12.5	52.5	82.6	**280.9**
RWM-NT	1.4	74.0	54.4	129.8	21.8	26.9	52.4	101.2	17.5	11.9	55.5	84.8	**315.8**

Option III													
	Retailer				Wholesaler				Manufacturer				**SC**
	H (£)	B (£)	O (£)	Total (£)	H (£)	B (£)	O (£)	Total (£)	H (£)	B (£)	O (£)	Total (£)	**Total (£)**
NI-S	1.9	50.0	54.7	106.7	12.9	12.6	54.3	79.7	56.6	0.6	56.3	113.5	**299.9**
NI-WH	1.8	48.6	54.8	105.3	8.0	10.4	52.3	70.7	51.6	0.3	56.5	108.5	**284.5**
NI-MF	1.8	51.2	54.8	107.8	12.2	12.9	54.4	79.5	53.4	0.2	53.2	106.8	**294.1**
NI-NT	1.8	49.0	54.8	105.6	8.2	10.9	54.7	73.7	51.8	0.3	56.2	108.4	**287.7**
RW-S	1.8	52.2	54.7	108.7	12.5	14.8	53.4	80.7	40.8	1.3	56.6	98.7	**288.1**
RW-WH	1.7	51.9	54.8	108.4	10.4	13.7	51.7	75.8	40.5	0.8	56.6	97.8	**282.1**
RW-MF	1.7	53.1	54.8	109.7	12.1	15.0	53.5	80.6	30.1	2.5	53.0	85.6	**275.8**
RW-NT	1.2	59.1	54.8	115.1	12.3	22.0	53.6	87.8	33.8	1.8	56.3	91.9	**294.8**
WM-S	1.7	57.4	54.7	113.9	10.5	20.4	54.3	85.2	13.6	16.6	55.3	85.5	**284.6**
WM-WH	1.6	54.1	54.8	110.6	6.4	16.3	52.3	75.0	14.3	11.7	55.3	81.3	**266.9**
WM-MF	1.5	60.4	54.8	116.8	9.3	22.8	54.4	86.4	9.9	19.7	52.5	82.2	**285.4**
WM-NT	1.5	56.7	54.8	113.1	6.1	19.2	54.7	79.9	11.9	15.6	55.1	82.7	**275.7**
RWM-S	1.8	53.4	54.7	109.9	11.8	16.2	53.4	81.3	23.6	5.0	57.9	86.5	**277.7**
RWM-WH	1.7	52.7	54.8	109.2	9.4	14.6	51.7	75.6	23.5	5.2	57.4	86.0	**270.9**
RWM-MF	1.7	53.8	54.8	110.3	11.8	15.7	53.5	81.0	19.4	4.2	54.1	77.7	**269.1**
RWM-NT	1.2	60.1	54.8	116.1	11.8	23.1	53.6	88.5	20.6	4.4	58.4	83.4	**287.9**

Fill rate performance (in %) of all the supply chain scenarios for options I, II and III.

	Option I			Option II			Option III		
	Retailer	Wholesaler	Manufacturer	Retailer	Wholesaler	Manufacturer	Retailer	Wholesaler	Manufacturer
NI-S	41.6	64.0	95.1	61.2	85.5	91.7	66.6	88.8	99.4
NI-WH	40.9	62.6	97.0	59.8	84.2	94.1	67.3	90.6	99.7
NI-MF	41.7	64.4	97.1	59.9	84.5	93.4	66.1	88.5	99.8
NI-NT	41.0	62.7	96.9	59.4	82.9	93.2	67.1	90.2	99.7
RW-S	46.1	75.6	78.9	67.0	90.9	94.7	65.7	87.1	98.8
RW-WH	46.2	75.8	79.0	63.8	93.3	95.6	65.8	87.9	99.2
RW-MF	46.2	76.0	79.0	63.1	91.5	95.8	65.3	87.0	97.6
RW-NT	43.6	69.1	78.9	58.3	80.5	95.4	62.9	82.0	98.3
WM-S	40.9	62.5	91.2	60.5	84.1	86.4	63.5	83.0	85.7
WM-WH	40.7	62.0	95.5	59.7	83.8	92.0	64.9	85.9	89.5
WM-MF	40.8	62.2	91.5	58.5	81.5	85.3	62.3	81.4	83.5
WM-NT	40.4	61.5	93.9	58.9	82.0	90.0	63.8	83.9	86.5
RWM-S	49.8	86.0	97.8	63.5	90.7	90.5	65.1	86.1	95.3
RWM-WH	50.4	88.2	99.1	65.5	87.3	95.1	65.5	87.3	95.1
RWM-MF	49.8	86.2	98.5	62.7	90.5	88.9	65.0	86.4	95.9
RWM-NT	46.6	77.1	98.9	57.5	78.8	89.4	62.5	81.2	95.8

APPENDIX 4.2 ORDERING PATTERN FOR ALL SUPPLY CHAIN SCENARIOS

Ordering Pattern of scenarios under the Serial Supply Chain Structure

OR- Ordering Rate (in decimal)

AEOQ- Average Effective Order Quantity (in units)

	NI					
	Retailer		Wholesaler		Manufacturer	
	OR	AEOQ	OR	AEOQ	OR	AEOQ
Option I	1.00	9.98	1.00	9.97	1.00	9.94
Option II	0.89	11.28	0.62	16.00	0.49	20.36
Option III	0.98	10.18	0.89	11.16	0.67	14.81
	RW					
	Retailer		Wholesaler		Manufacturer	
	OR	AEOQ	OR	AEOQ	OR	AEOQ
Option I	1.00	9.98	1.00	9.98	1.00	9.96
Option II	0.89	11.28	0.50	20.00	0.49	20.38
Option III	0.98	10.18	0.71	14.04	0.69	14.53
	WM					
	Retailer		Wholesaler		Manufacturer	
	OR	AEOQ	OR	AEOQ	OR	AEOQ
Option I	1.00	9.98	1.00	9.97	1.00	9.97
Option II	0.89	11.28	0.62	16.00	0.39	25.30
Option III	0.98	10.18	0.89	11.16	0.55	18.01
	RWM					
	Retailer		Wholesaler		Manufacturer	
	OR	AEOQ	OR	AEOQ	OR	AEOQ
Option I	1.00	9.98	1.00	9.98	1.00	9.97
Option II	0.89	11.28	0.50	20.00	0.55	18.00
Option III	0.98	10.18	0.71	14.04	0.81	12.27

Ordering Pattern of scenarios under the Wholesaler Supply Chain Structure

	NI					
	Retailer		Wholesaler		Manufacturer	
	OR	AEOQ	OR	AEOQ	OR	AEOQ
Option I	1.00	10.00	1.00	9.99	1.00	9.96
Option II	0.99	10.09	0.69	14.50	0.62	16.01
Option III	1.00	10.00	0.96	10.37	0.75	13.29
	RW					
	Retailer		Wholesaler		Manufacturer	
	OR	AEOQ	OR	AEOQ	OR	AEOQ
Option I	1.00	10.00	1.00	10.00	1.00	9.98
Option II	0.99	10.09	0.48	20.95	0.50	20.03
Option III	1.00	10.00	0.70	14.26	0.69	14.43
	WM					
	Retailer		Wholesaler		Manufacturer	
	OR	AEOQ	OR	AEOQ	OR	AEOQ
Option I	1.00	10.00	1.00	9.99	1.00	9.99
Option II	0.99	10.09	0.69	14.50	0.63	15.99
Option III	1.00	10.00	0.96	10.37	0.69	14.54
	RWM					
	Retailer		Wholesaler		Manufacturer	
	OR	AEOQ	OR	AEOQ	OR	AEOQ
Option I	1.00	10.00	1.00	10.00	1.00	9.99
Option II	0.99	10.09	0.48	20.95	0.82	12.25
Option III	1.00	10.00	0.70	14.26	0.98	10.22

Ordering Pattern of scenarios under the Manufacturer Supply Chain Structure

	NI					
	Retailer		Wholesaler		Manufacturer	
	OR	AEOQ	OR	AEOQ	OR	AEOQ
Option I	1.00	10.00	1.00	9.99	1.00	9.96
Option II	0.99	10.09	0.86	11.62	0.48	21.01
Option III	1.00	10.00	0.99	10.11	0.69	14.38
	RW					
	Retailer		Wholesaler		Manufacturer	
	OR	AEOQ	OR	AEOQ	OR	AEOQ
Option I	1.00	10.00	1.00	10.00	1.00	9.98
Option II	0.99	10.09	0.75	13.25	0.48	21.01
Option III	1.00	10.00	0.92	10.91	0.63	15.76
	WM					
	Retailer		Wholesaler		Manufacturer	
	OR	AEOQ	OR	AEOQ	OR	AEOQ
Option I	1.00	10.00	1.00	9.99	1.00	9.99
Option II	0.99	10.09	0.86	11.62	0.39	25.50
Option III	1.00	10.00	0.99	10.11	0.53	18.69
	RWM					
	Retailer		Wholesaler		Manufacturer	
	OR	AEOQ	OR	AEOQ	OR	AEOQ
Option I	1.00	10.00	1.00	10.00	1.00	9.99
Option II	0.99	10.09	0.75	13.25	0.53	19.00
Option III	1.00	10.00	0.92	10.91	0.84	11.89

Ordering Pattern of scenarios under the Network Supply Chain Structure

	NI					
	Retailer		Wholesaler		Manufacturer	
	OR	AEOQ	OR	AEOQ	OR	AEOQ
Option I	1.00	10.00	1.00	9.99	1.00	9.96
Option II	0.99	10.09	0.88	11.41	0.67	14.99
Option III	1.00	10.00	0.96	10.36	0.73	13.65
	RW					
	Retailer		Wholesaler		Manufacturer	
	OR	AEOQ	OR	AEOQ	OR	AEOQ
Option I	1.00	10.00	1.00	10.00	1.00	9.98
Option II	0.99	10.09	0.75	13.34	0.50	20.08
Option III	1.00	10.00	0.85	11.72	0.68	14.76
	WM					
	Retailer		Wholesaler		Manufacturer	
	OR	AEOQ	OR	AEOQ	OR	AEOQ
Option I	1.00	10.00	1.00	9.99	1.00	9.99
Option II	0.99	10.09	0.88	11.41	0.62	16.01
Option III	1.00	10.00	0.96	10.36	0.68	14.80
	RWM					
	Retailer		Wholesaler		Manufacturer	
	OR	AEOQ	OR	AEOQ	OR	AEOQ
Option I	1.00	10.00	1.00	10.00	1.00	9.99
Option II	0.99	10.09	0.75	13.34	0.70	14.70
Option III	1.00	10.00	0.85	11.72	0.93	10.68

APPENDIX 4.3 BULLWHIP QUANTIFICATION OF ALL SCENARIOS

Structure Effect on Order Amplification In A Non-Breach Scenario

The variance of all orders at each tier of the supply chain in the non-breach scenario under the various supply chain structures

		Order variance at each tier			
		Serial	WH	MF	NT
Op. I	Demand	4.11	4.26	4.26	4.26
	R Order	4.23	4.24	4.24	4.24
	W Order	4.42	4.41	4.42	4.40
	M Order	4.57	4.57	4.56	4.55
Op. II	Demand	4.11	4.26	4.26	4.26
	R Order	12.90	11.33	11.33	11.33
	W Order	60.13	90.18	59.79	51.51
	M Order	103.99	154.79	220.43	136.16
Op. III	Demand	4.11	4.26	4.26	4.26
	R Order	6.17	5.88	5.88	5.88
	W Order	18.20	14.78	18.19	16.09
	M Order	61.20	100.85	110.05	108.98

The order amplification at the retailer, wholesaler and manufacturer computed as a ratio to the demand variance (Chen at al. 2000a).

Order Amplification Relative to Demand variance					
		Serial	WH	MF	NT
Option I	Retailer	1.03	1.00	1.00	1.00
	Wholesaler	1.07	1.04	1.04	1.03
	Manufacturer	1.11	1.07	1.07	1.07
Option II	Retailer	3.14	2.66	2.66	2.66
	Wholesaler	14.63	21.19	14.05	12.10
	Manufacturer	25.30	36.37	51.80	32.00
Option III	Retailer	1.50	1.38	1.38	1.38
	Wholesaler	4.43	3.47	4.27	3.78
	Manufacturer	14.89	23.70	25.86	25.61

The order amplification at the retailer, wholesaler and manufacturer computed as a ratio to the order variance of the adjacent downstream tier, Control Theory (Jury 1974).

	Order Amplification based on Control Theory				
		Serial	WH	MF	NT
Option I	Retailer	1.03	1.00	1.00	1.00
	Wholesaler	1.04	1.04	1.04	1.04
	Manufacturer	1.03	1.03	1.03	1.03
Option II	Retailer	3.14	2.66	2.66	2.66
	Wholesaler	4.66	7.96	5.28	4.55
	Manufacturer	1.73	1.72	3.69	2.64
Option III	Retailer	1.50	1.38	1.38	1.38
	Wholesaler	2.95	2.51	3.09	2.74
	Manufacturer	3.36	6.82	6.05	6.77

Information Sharing Level Effect on Order Amplification in A Non-Breach Scenario

The variance of all orders at each tier of the serial supply chain in the non-breach scenario under the various supply information sharing levels.

	Order variance under each ISL				
		NI	RW	WM	RWM
Option I	Demand	4.11	4.11	4.11	4.11
	R Order	4.23	4.23	4.23	4.23
	W Order	4.42	4.36	4.42	4.36
	M Order	4.57	4.48	4.55	4.19
Option II	Demand	4.11	4.11	4.11	4.11
	R Order	12.90	12.90	12.90	12.90
	W Order	60.13	100.14	60.13	100.14
	M Order	103.99	104.20	153.19	80.20
Option III	Demand	4.11	4.11	4.11	4.11
	R Order	6.17	6.17	6.17	6.17
	W Order	18.20	50.39	18.20	50.39
	M Order	61.20	56.98	87.35	31.19

The order amplification at the retailer, wholesaler and manufacturer computed as a ratio to the demand variance (Chen at al. 2000a).

	Order Amplification Relative to Demand variance				
		NI	RW	WM	RWM
Option I	Retailer	1.03	1.03	1.03	1.03
	Wholesaler	1.07	1.06	1.07	1.06
	Manufacturer	1.11	1.09	1.11	1.02
Option II	Retailer	3.14	3.14	3.14	3.14
	Wholesaler	14.63	24.36	14.63	24.36
	Manufacturer	25.30	25.35	37.26	19.51
Option III	Retailer	1.50	1.50	1.50	1.50
	Wholesaler	4.43	12.26	4.43	12.26
	Manufacturer	14.89	13.86	21.25	7.59

The order amplification at the retailer, wholesaler and manufacturer computed as a ratio to the order variance of the adjacent downstream tier, Control Theory (Jury 1974).

	Order Amplification based on Control Theory				
		NI	RW	WM	RWM
Option I	Retailer	1.03	1.03	1.03	1.03
	Wholesaler	1.04	1.03	1.04	1.03
	Manufacturer	1.03	1.03	1.03	0.96
Option II	Retailer	3.14	3.14	3.14	3.14
	Wholesaler	4.66	7.76	4.66	7.76
	Manufacturer	1.73	1.04	2.55	0.80
Option III	Retailer	1.50	1.50	1.50	1.50
	Wholesaler	2.95	8.17	2.95	8.17
	Manufacturer	3.36	1.13	4.80	0.62

APPENDIX 4.4 INTERACTION EFFECT OF INFORMATION SHARING STRATEGIES AND STRUCTURAL RECONFIGURATION STRATEGIES

Singular effect and Interaction effect of information sharing level and supply chain structure on supply chain daily operational cost performance ('nd' means not statistically significant at p<0.05)

		Option I				Option II				Option III			
		Ret. (%)	Whole. (%)	Manuf. (%)	SC Total (%)	Ret. (%)	Whole. (%)	Manuf. (%)	SC Total (%)	Ret. (%)	Whole. (%)	Manuf. (%)	SC Total (%)
Singular effect of Structure	WH	-2.1nd	0.2nd	5.3	0.2nd	-3.1	8	7.1	3.4	1.3nd	11.3	4.4	5.2
	MF	0.1nd	0.6nd	11	2.7nd	-2.8nd	-0.4nd	12.8	3.1	-1	0.3	5.9	1.9
	NT	-2.0nd	-1.9nd	5.2	-0.4nd	-3.9	4.6	12.5	3.9	1.0nd	7.5	4.5	4.1
Singular effect of Integration	RW	12.1	18.1	-3.1nd	10.4	5.1	4.4	-2.3nd	2.5	-1.9	-1.2nd	13	3.9
	WM	-2	-3.2	13.3	1.1nd	-1.5	-0.8	7.5	1.7	-6.7	-6.9	24.7	5.1
	RWM	20.2	30.1	10.9	20.9	4.8	5.8	11.4	7.3	-3	-2	23.8	7.4
RW and structure synergy	WH	12.1	23	-0.6nd	12.3	5.2	9.6	-5.5	2.9	-1.7nd	4.9	13.8	5.9
	MF	12.1	18.9	5.2nd	12.5	3.8nd	4.5	8.7	5.6	-2.8nd	-1.0nd	24.6	8
	NT	5.5	5.9	-0.7nd	4.2	-6.4	-15	8.2	-3.9	-7.9	-10.2	19	1.7nd
WM and structure synergy	WH	-2.9	-1.1nd	17.5	2.2nd	-3.4	8.2	10.6	4.5	-3.6	5.9	28.3	11
	MF	-2.7nd	-3.9nd	23.2	2.8nd	-6.1	-3.3	13.8	1.3nd	-9.5	-8.4	27.6	4.8
	NT	-3.7	-4.7nd	18.7	1.1nd	-4.9	3.8	13	3.5	-6	-0.3nd	27.2	8.1
RWM and structure synergy	WH	21.4	37.6	10.5	23.5	5.1	12.3	10.8	9	-2.3nd	5.1	24.2	9.7
	MF	20	30.3	22.2	23.4	3.1nd	5.6	19.7	9.3	-3.4	-1.6	31.5	10.3
	NT	13.1	16.5	14.6	14.4	-8.2	-16.5	17.6	-1.9	-8.8	-11	26.6	4

Nature of Interaction Effect

		RW			WM			RWM		
		WH	MF	N	WH	MF	N	WH	MF	N
Option I	Retailer	CA+	CO	CA+	W	CA-	W	CA+	CO	CA+
	Wholesaler	CO	CO	CA+	CA-	CA-	W	CO	CO	CA+
	Manufacturer	CA-	CA+	CA-	CO	CO	CO	CO	CO	CO
	SC Total	CO	CO	CA+	CO	CO	CA+	CO	CO	CA+
Option II	Retailer	CA+	CA+	CA-	W	W	W	CA+	CA+	CA-
	Wholesaler	CO	CA+	R-	CA+	W	CA+	CO	CA+	R-
	Manufacturer	CA-	CA+	CA+	CO	CO	CO	CO	CO	CO
	SC Total	CO	CO	R-	CO	CO	CO	CO	CO	R-
Option III	Retailer	CA-	W	CA-	CA-	W	CA-	CA-	W	CA-
	Wholesaler	CA+	CA-	CA-	CA+	CA-	CA-	CA+	CA-	CA-
	Manufacturer	CO	CO	CO	CO	CO	CO	CO	CO	CO
	SC Total	CO	CO	CO	CO	CO	CO	CO	CO	CO

Positive cancellation (CA+) means the resultant effect is beneficial produced from a positive ISL and negative Structure or a negative ISL and a positive Structure effect. A negative cancellation (CA-) occurs when the resultant effect is negative produced either from a positive ISL and negative Structure effect or vice versa. A negative repelling effect (R-) occurs when the positive effect of both ISL and Structure produces a resultant negative effect. On the other hand a positive repelling effect (R+) occurs when the negative effect of both ISL and Structure produces a resultant positive effect. Worsening effect (W) is generated when the resultant effect is negative which is produced from both negative ISL and Structure effects and a corroborating effect (CO) is felt when the resultant effect is positive produced from a positive ISL and a positive Structure effect.

CO, CA+, and R+ symbols are all beneficial effects but CA-, R- and W are all detrimental effects.

APPENDIX 5.1 INTERACTION EFFECT OF ISL AND SUPPLY STRUCTURE UNDER INFORMATION SECURITY BREACH

Interaction effect under SFDD ('*' means not statistically significant at p<0.05)

		option I				option II				option III			
		R. Cost %	W. Cost %	M. Cost %	SC Total %	R. Cost %	W. Cost %	M. Cost %	SC Total %	R. Cost %	W. Cost %	M. Cost %	SC Total %
Singular effect of Structure	WH	-4	6	19	4	60	21	10	32	10	30	13	16
	MF	-4	2	25	4	60	13	15	32	8	18	16	14
	NT	-4	4	19	3	58	16	15	32	9	27	13	15
Singular effect of Integration	RW	0	0	8	2	22	-8	-14	2	-8	-1	10	1
	WM	-2	-4	12	1	-4	-5	7	0	-7	-7	22	4
	RWM	4	5	4	4	21	-1	-11	4	-10	-4	18	2
RW and structure synergy	WH	3.1	17.2	16.2	10.7	77.1	16.2	-4.4	32.9	5.5	24.5	22.0	16.8
	MF	2.8	11.8	9.3	10.3	74.6	9.3	7.8	34.1	3.6	16.7	32.0	17.9
	NT	-0.4	4.6*	7.8	2.5	75.1	7.8*	-0.7	31.0	7.4*	17.4	3.7	8.6
WM and structure synergy	WH	-5.1	4.6	20.0	4.8	59.1	20.0	13.3	32.9	5.7	26.0	34.5	22.0
	MF	-7.4	-4.0	7.5	3.0	55.6	7.5	15.5	28.8	-0.4*	9.7	33.8	15.3
	NT	-6.0	0.6*	14.2	4.1	56.7	14.2	15.3	31.0	3.5	20.4	34.2	19.6
RWM and structure synergy	WH	9.3	26.8	27.3	16.0	76.7	27.3	-13.8	32.8	3.5	22.3	28.0	17.8
	MF	8.1	19.2	11.7	16.9	73.2	11.7	14.8	36.6	2.1	14.9	37.9	19.0
	NT	3.0	9.0	4.2	9.7	69.4	4.2	10.9	31.7	-1.0*	8.8	32.6	14.3

Interaction effect under AOW ('*' means not statistically significant at p<0.05)

		option I				option II				option III			
		R. Cost %	W. Cost %	M. Cost %	SC Total %	R. Cost %	W. Cost %	M. Cost %	SC Total %	R. Cost %	W. Cost %	M. Cost %	SC Total %
Singular effect of Structure	WH	-10	-2	5	-5	8	9	7	8	-4	13	4	4
	MF	-12	-8	11	-6	8	1	13	8	-1	6	9	5
	NT	-10	-4	5	-5	7	6	12	9	-4	11	5	3
Singular effect of Integration	RW	6	2	12	6	12	-6	-2	2	4	0	13	6
	WM	-2	-7	0	-3	-2	-1	7	1	0	-2	16	6
	RWM	8	6	-3	5	11	2	-2	4	3	1	19	9
RW and structure synergy	WH	-1.5*	9.6	7.4	3.6	20.0	7.4	-5.5	8.0	1.4*	14.8	16.8	10.8
	MF	-2.2	3.5	0.5	2.8	18.2	0.5*	8.0	9.8	-0.3*	5.7	27.7	11.9
	NT	-4.5	1.7	-9.0	-0.1	13.7	-9.0	0.3	2.9	-2.5	2.4*	4.2	1.3
WM and structure synergy	WH	-11.7	-5.2	9.4	-5.0	7.8	9.4	10.3	9.1	-4.6	13.1	26.8	12.0
	MF	-15.4	-15.1	-2.3	-8.5	5.0*	-2.3	13.4	5.7	-6.1	3.7	28.8	9.7
	NT	-12.8	-9.8	5.2	-6.3	6.3	5.2	12.7	8.1	-5.6	9.3	27.2	10.8
RWM and structure synergy	WH	3.5	17.6	13.3*	7.3	19.8	13.3	4.9	13.0	1.3*	15.7	25.8	14.4
	MF	2.0	9.5	3.1	7.5	16.5	3.1	13.2	11.7	-1.3*	5.9	31.5	13.0
	NT	-2.1	1.3*	-10.6	1.4	9.3	-10.6	11.9	4.6	-3.5	0.5*	26.5	8.9

Interaction effect under PT ('*' means not statistically significant at p<0.05)

		option I				option II				option III			
		R. Cost %	W. Cost %	M. Cost %	SC Total %	R. Cost %	W. Cost %	M. Cost %	SC Total %	R. Cost %	W. Cost %	M. Cost %	SC Total %
Singular effect of Structure	WH	-5	-2	6	-2	0	9	7	5	-1	11	4	4
	MF	-3	-2	11	1	0	0	13	4	-3	0	6	2
	NT	-5	-4	6	-2	-1	6	13	5	-1	7	4	3
Singular effect of Integration	RW	10	15	-1	9	7	4	-3	3	-3	-2	13	3
	WM	-2	-3	13	1	-2	-1	8	2	-6	-6	25	6
	RWM	17	25	10	18	7	6	11	8	-4	-2	24	7
RW and structure synergy	WH	8.2	18.7	10.8*	9.4	8.9	10.8	-5.1	4.8	-3.7	5.0	14.2	5.4
	MF	8.4	14.7	5.4	9.7	7.5	5.4	8.9	7.4	-4.7	-1.1	24.8	7.4
	NT	3.6*	4.7*	-11.7*	0.3*	-0.5*	-11.7	1.0	-3.2*	-3.9	-4.3	-5.4	-4.6*
WM and structure synergy	WH	-5.3	-2.9*	9.2	0.8*	-0.5*	9.2	10.9	6.0	-5.0	6.5	29.2	11.0
	MF	-5.6	-6.7	-2.6	0.5*	-3.3*	-2.6	14.0	2.6	-10.3	-7.3	28.1	5.0
	NT	-6.5	-7.3	4.8	-1.0*	-2.1*	4.8	13.3	4.9	-7.5	0.3*	27.7	7.9
RWM and structure synergy	WH	17.0	32.4	13.9	19.8	8.7	13.9	10.4	10.7	-4.3	5.2	24.4	9.1
	MF	15.7	25.2	6.6	19.9	6.7	6.6	19.4	10.9	-5.4	-1.7	31.7	9.6
	NT	9.0	11.9	-14.3	11.1	-3.9*	-14.3	17.5	0.3*	-10.7	-10.8	26.8	3.5

Interaction effect under IBMS ('*' means not statistically significant at p<0.05)

		option I				option II				option III			
		R. Cost %	W. Cost %	M. Cost %	SC Total %	R. Cost %	W. Cost %	M. Cost %	SC Total %	R. Cost %	W. Cost %	M. Cost %	SC Total %
Singular effect of Structure	WH	-4	-1	6	-1	-1	9	7	4	0	11	4	4
	MF	-2	-1	11	1	-1	0	13	4	-2	0	6	2
	NT	-4	-4	5	-2	-2	5	13	5	-1	7	5	3
Singular effect of Integration	RW	10	15	-2	9	6	4	-2	3	-3	-2	13	3
	WM	-2	-3	13	1	-2	-1	8	2	-6	-6	25	6
	RWM	18	26	10	19	6	6	11	8	-4	-3	24	7
RW and structure synergy	WH	9.2	20.0	10.3*	10.2	7.3	10.3	-5.1	4.0	-3.4	4.8	14.1	5.4
	MF	9.4	16.0	5.0	10.5	5.9	5.0	8.9	6.7	-4.5	-1.3*	24.8	7.4
	NT	4.6*	5.9*	-12.9*	1.0*	-2.4*	-12.9	1.0	-4.2	-3.4	-4.2	-5.4	-4.4*
WM and structure synergy	WH	-4.6	-2.2*	8.8	1.2*	-1.7*	8.8	10.9	5.4	-4.8	6.2	28.9	10.9
	MF	-4.8	-5.8	-2.8	1.2*	-4.5	-2.8	14.0	2.1	-10.3	-7.9	27.8	4.8
	NT	-5.7	-6.4	4.4	-0.4*	-3.3	4.4	13.3	4.4	-7.3	0.0*	27.5	7.8
RWM and structure synergy	WH	18.2	34.1	13.2	20.9	7.1	13.2	10.6	10.0	-4.0	5.0	24.3	9.1
	MF	17.0	26.9	6.2	21.0	5.1*	6.2	19.7	10.3	-5.2	-1.9	31.6	9.6
	NT	10.2	13.3	-15.3	12.1	-5.8*	-15.3	17.6	-0.7*	-10.5	-11.1	26.7	3.4

Aggregate of interaction effect under all four information security breaches

		option I				option II				option III			
		R. Cost %	W. Cost %	M. Cost %	SC Total %	R. Cost %	W. Cost %	M. Cost %	SC Total %	R. Cost %	W. Cost %	M. Cost %	SC Total %
Singular effect of Structure	WH	-23	1	35	-3	66	48	32	50	5	65	27	29
	MF	-20	-9	58	1	67	14	53	48	2	26	37	22
	NT	-23	-8	35	-6	62	33	53	51	4	51	27	25
Singular effect of Integration	RW	27	32	17	26	48	-5	-21	10	-10	-5	49	14
	WM	-8	-17	38	0	-8	-8	29	4	-18	-20	88	22
	RWM	47	62	21	45	45	14	9	24	-14	-8	84	25
RW and structure synergy	WH	19	65	45	34	113	45	-20	50	0	49	67	38
	MF	18	46	20	33	106	20	34	58	-6	20	109	45
	NT	3	17	-26	4	86	-26	1	27	-2	11	-3	1
WM and structure synergy	WH	-27	-6	47	2	65	47	45	53	-9	52	119	56
	MF	-33	-32	0	-4	53	0	57	39	-27	-2	119	35
	NT	-31	-23	29	-4	58	29	54	48	-17	30	117	46
RWM and structure synergy	WH	48	111	68	64	112	68	12	66	-4	48	102	50
	MF	43	81	28	65	101	28	67	69	-10	17	133	51
	NT	20	36	-36	34	69	-36	58	36	-26	-13	113	30

APPENDIX 5.2 COMPARISON OF THE NATURE OF INTERACTION EFFECT UNDER BREACH AND NON-BREACH SCENARIOS

Since this section is only concerned with the analysis of the interaction between ISL and structure, an examination of the interaction effect in Appendix 5.1 reveals the state or categories of the types of interaction effect which is presented in the subsequent tables in this section. The state/categories of the types of interaction has been described in section 4.4.4 and these are cancellation effect (which can be positive or negative), repelling effect (which can be positive or negative), worsening effect and corroborating effect. A cancellation effect is observed when an agent is favoured by structural reconfiguration and disfavoured by ISL or the other way round. A positive cancellation effect is observed when the resultant cancellation effect yields improvement in performance and a negative cancellation effect is observed when the resultant effect worsens the performance. The repelling effect occurs when both ISL and reconfiguration are of the same nature either positive or negative producing the opposite effect when combined. Therefore a positive repelling effect produces a positive effect from the negative effects of ISL and reconfiguration while a negative repelling effect produces a negative effect from the positive effects of both ISL and structural reconfiguration. A worsening effect is observed when both structural reconfiguration and ISL do not favour the supply agent, hence the agent would have been better off in a serial supply chain where no information is being shared. A corroborating effect is the case when both structure and ISL favour the agent.

Interacting Effect of RW and Supply Chain Structure in a Breach Scenario

To address the two issues stated in section 5.5, the categories of the interaction effect between RW and supply chain structure is shown in the table below. The categories of RW+Structure interaction effect under the non-breach scenario is extracted from Appendix 4.4 and is included for comparison purpose in the table below. Those of the breach scenarios are deduced from Appendix 5.1. The table below therefore paints the picture of

how the effect categories changes from a non-breach state to a less disruptive and less recurring breach scenario and how this changes when the disruption duration and the RoC increases significantly.

Under the impact of IBMS, the state or category of the interaction between RW and structure on supply chain total operating cost remains the same for options II and III as under a non-breach scenario. However, under option I, this changes for the RW+WH interaction from the desirable CO (collaborating effect) in the non-breach context to a less desirable CA+ (positive cancellation) in the breach scenario. When the disruption duration is intensified the state of the interaction of RW with the WH and MF structure is similar to the non-breach scenario but that of the network structure changes from the less desirable CA+ in the non-breach scenario to the more desirable CO in the SFDD breach counterpart. A breach with increased RoC such as is the case of AOW would cause a state change in the interaction effect for all supply chain structures under option I scenario. CO, CO, CA+ for WH, MF and N respectively changes to CA+, CA+, CA- in the highly recurring breach state. Under option II, the result also shows that a breach with less disruptive tendencies and less recurring nature have no effect on the state of interaction between RW and structure. However when the disruption duration and RoC increases significantly, the state of interaction between RW and N changes from a less desirable R- to a more desirable CO. Option III represents a more stable policy in this regard. Regardless of the breach profile, the state of the interaction between RW and Structure is not changed for option III.

When the result in Appendix 4.4 is compared to the result in Appendix 5.1, it clear that the magnitude of RW+ structure effect is reduced under a breach scenario (IBMS) for options I and III but that of option II is actually increased. Hence the benefit of the interaction effect under IBMS security breach is higher for option II but lower for options I and III.

Interaction effect between RW and Structure and the effect of security breach profile

	Option I				Option II				Option III			
	Retailer	Wholesaler	Manufacturer	SC	Retailer	Wholesaler	Manufacturer	SC	Retailer	Wholesaler	Manufacturer	SC
Non-Breach Scenario												
WH	CA+	CO	CA-	CO	CA+	CO	CA-	CO	CA-	CA+	CO	CO
MF	CO	CO	CA+	CO	CA+	CA+	CA+	CO	W	CA-	CO	CO
N	CA+	CA+	CA-	CA+	CA-	R-	CA+	R-	CA-	CA-	CO	CO
Less Disruptive and Less Recurring Breach (IBMS) Scenario												
WH	CA+	CA+	CA+	CA+	CA+	CO	CA-	CO	W	CA+	CO	CO
MF	CA+	CA+	CA+	CO	CA+	CO	CA+	CO	W	CA-	CO	CO
N	CA+	CA+	CA+	CA+	CA-	R-	CA+	R-	W	CA-	CO	CO
High Disruptive and Less Recurring Breach (SFDD) Scenario												
WH	CA+	CA+	CO	CO	CO	CA+	CA-	CO	CA+	CA+	CO	CO
MF	CA+	CA+	CO	CO	CO	CA+	CA+	CO	CA+	CA+	CO	CO
N	CA-	CA+	CO	CO	CO	CA+	CA+	CO	CA+	CA+	CO	CO
Less Disruptive but High Recurring Breach (AOW) Scenario												
WH	CA-	CA+	CO	CA+	CO	CA+	CA-	CO	CA+	CA+	CO	CO
MF	CA-	CA+	CO	CA+	CO	CA+	CA+	CO	CA-	CA+	CO	CO
N	CA-	CA-	CO	CA-	CO	CA-	CA+	CO	CA-	CA+	CO	CO

Further examination reveals that this benefit tend to increase when the security breach has higher disruptive tendencies or RoC for option II and for option III, with the exception of the WH structure under option II where the magnitude of interaction effect is negative and less than the non-breach counterpart.

Interacting Effect of WM and Supply Chain Structure in a Breach Scenario

The change in the state of interaction effect between WM and Structure due to information security breach profile is shown in the table below. In a less disruptive and less recurring security breach scenario, the state of the interaction between WM and structure under options II and III remains unchanged while that of option I is changed from a more desirable state to a less desirable type for WH and N structures only. Under option I, only the state of WM+N is changed from CA+ to CO under a more disruptive breach while the state of WM+WH and WM+MF remains the same. In a more recurring breach scenario, the state of all three structures under the influence of WM changes to W which is a worsening effect. However, for option II, breaches of type SFDD causes a change in state for all structure types from CO in the non-breach scenario to CA+ in the SFDD breach scenario but breaches of the type AOW do not effect any changes to the state of the interaction between WM and all structure types discussed in this study. Again the state of the WM+Structure interaction under option III appear to be unperturbed by the incidence of security breach regardless of the breach profile. The corroborating interaction effect remains unchanged despite increasing recurring rate and disruption duration.

A comparison of the result for WM in Appendix 4.4 with the result for WM shown in Appendix 5.1 reveals that for a breach profile similar to IBMS profile, the magnitude of WM+Structure interaction effect is higher under option II, while lower under option I but somewhat stable under option III.

Interaction effect between WM and Structure and the effect of security breach profile

	Option I				Option II				Option III			
	Retailer	Wholesaler	Manufacturer	SC	Retailer	Wholesaler	Manufacturer	SC	Retailer	Wholesaler	Manufacturer	SC
Non-Breach Scenario												
WH	W	CA-	CO	CO	W	CA+	CO	CO	CA-	CA+	CO	CO
MF	CA-	CA-	CO	CO	W	W	CO	CO	W	CA-	CO	CO
N	W	W	CO	CA+	W	CA+	CO	CO	CA-	CA-	CO	CO
Less Disruptive and Less Recurring Breach (IBMS) Scenario												
WH	W	W	CO	CA+	W	CA+	CO	CO	W	CA+	CO	CO
MF	W	W	CO	CO	W	CA-	CO	CO	W	CA-	CO	CO
N	W	W	CO	CA-	W	CA+	CO	CO	W	CA-	CO	CO
High Disruptive and Less Recurring Breach (SFDD) Scenario												
WH	W	CA+	CO	CO	CA+	CA+	CO	CA+	CA+	CA+	CO	CO
MF	W	CA-	CO	CO	CA+	CA+	CO	CA+	CA-	CA+	CO	CO
N	W	CA+	CO	CO	CA+	CA+	CO	CA+	CA+	CA+	CO	CO
Less Disruptive but High Recurring Breach (AOW) Scenario												
WH	W	W	CA+	W	CA+	CA+	CO	CO	CA-	CA+	CO	CO
MF	W	W	CA+	W	CA+	CA-	CO	CO	CA-	CA+	CO	CO
N	W	W	CA+	W	CA+	CA+	CO	CO	CA-	CA+	CO	CO

Therefore WM+Structure interaction benefit is higher under a less disruptive and less disruptive breach only for option II. The story changes when the breach profile is of the SFDD type causing the magnitude of the WM+Structure interaction effect to be greater under all three ordering options (I, II and III). It therefore shows that a combination of WM and structural reconfiguration offers greater benefit to the supply chain in highly disruptive breach scenario than in the non-breach scenario. This study does not try to infer that a security breach scenario is more desirable but only demonstrates that the supply chain can with this WM+Structure combination can rest assured that they would be protected even better in a security breach state with SFDD type profile. A highly recurring breach type however worsens the interaction effect under option I producing a negative result but the performance under options II and III is improved under this breach profile.

Interacting Effect of RWM and Supply Chain Structure in a Breach Scenario

The result for the effect of security breach profile on the state of RWM+Structure interaction effect is shown in the table below. Again the state change from non-breach scenario to a less disruptive and less recurring breach scenario is first examined and then the state change under increased disruption duration and increased recurring rate is then examined. Under IBMS type profile, only the combination that involves WH is affected with a change in state from CO to CA+ in the option I scenario. However the state in the options II and III scenarios are unaffected. With a more disruptive breach, only the network structure combination is affected, however only under options I (CA+ to CO) and II (R- to CO) scenarios. A less disruptive but highly recurring breach is seen to cause a change in state of the WH and MF combinations from CO to CA+ under option I scenario. However this produces a change only under the N structure from R- to CO in the option II scenario. Again the state of all combinations under option III scenario remain unperturbed by breach profile.

Interaction effect between RWM and Structure and the effect of security breach profile

	Option I				Option II				Option III			
	Retailer	Wholesaler	Manufacturer	SC	Retailer	Wholesaler	Manufacturer	SC	Retailer	Wholesaler	Manufacturer	SC
Non-Breach Scenario												
WH	CA+	CO	CO	CO	CA+	CO	CO	CO	CA-	CA+	CO	CO
MF	CO	CO	CO	CO	CA+	CA+	CO	CO	W	CA-	CO	CO
N	CA+	CA+	CO	CA+	CA-	R-	CO	R-	CA-	CA-	CO	CO
Less Disruptive and Less Recurring Breach (IBMS) Scenario												
WH	CA+	CA+	CO	CA+	CA+	CO	CO	CO	W	CA+	CO	CO
MF	CA+	CA+	CO	CO	CA+	CO	CO	CO	W	CA-	CO	CO
N	CA+	CA+	CO	CA+	CA-	R-	CO	R-	W	CA-	CO	CO
High Disruptive and Less Recurring Breach (SFDD) Scenario												
WH	CA+	CO	CO	CO	CO	CA+	CA-	CO	CA+	CA+	CO	CO
MF	CA+	CO	CO	CO	CO	CA+	CA+	CO	CA+	CA+	CO	CO
N	CA+	CO	CO	CO	CO	CA+	CA+	CO	CA-	CA+	CO	CO
Less Disruptive but High Recurring Breach (AOW) Scenario												
WH	CA+	CA+	CA+	CA+	CO	CO	CA+	CO	CA+	CO	CO	CO
MF	CA+	CA+	CA+	CA+	CO	CO	CA+	CO	CA-	CO	CO	CO
N	CA-	CA+	CA+	CA+	CO	R-	CA+	CO	CA-	CO	CO	CO

In summary, the state of interaction between RWM and structure is not affected by changing breach profile for an option III supply chain but that of the option II is changed only for the Network structure under conditions of high disruption duration and high RoC. For option I, the change comes for the WH structure combination only under IBMS and AOW breach profiles, for MF the change comes only under AOW breach profile and for N the only change seen comes under SFDD breach type.

APPENDIX 6.1 UNCERTAINTY RATING UNDER SUPPLY CHAIN STRUCTURE

Uncertainty rating in a Parameter based ordering system (Option I).

WH STRUCTURE										
	Retailer			Wholesaler			Manufacturer			SC
	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	1	0	1	0	0	0	0	0	0	0
AOW	1	0	1	0	0	0	0	0	0	0
PT	1	0	1	0	0	0	0	1	1	0
IBMS	1	0	1	1	0	1	0	1	1	1
MF STRUCTURE										
	Retailer			Wholesaler			Manufacturer			SC
	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	1	0	1	1	0	1	0	0	0	0
AOW	1	0	1	0	0	0	0	0	0	0
PT	1	0	1	0	0	0	0	1	1	0
IBMS	1	1	1	1	1	1	3	1	2	1
NT STRUCTURE										
	Retailer			Wholesaler			Manufacturer			SC
	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	1	0	1	0	0	0	0	0	0	0
AOW	1	0	1	0	0	0	0	0	0	0
PT	1	0	1	0	0	0	0	1	1	0
IBMS	1	0	1	1	0	1	0	1	1	1

Uncertainty rating in a Batch ordering system (Option II).

WH										
	Retailer			Wholesaler			Manufacturer			SC
	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	0	3	2	0	0	0	1	0	1	1
AOW	1	0	1	1	1	1	1	1	1	1
PT	1	1	1	1	1	1	1	1	1	1
IBMS	1	1	1	1	1	1	1	1	1	1
MF										
	Retailer			Wholesaler			Manufacturer			SC
	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	0	3	2	0	0	0	1	1	1	1
AOW	1	0	1	1	1	1	1	1	1	1
PT	1	1	1	1	1	1	1	1	1	1
IBMS	1	1	1	1	1	1	1	1	1	1
NT										
	Retailer			Wholesaler			Manufacturer			SC
	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	0	3	2	0	0	0	1	0	1	1
AOW	1	0	1	1	1	1	1	1	1	1
PT	1	1	1	1	1	1	1	1	1	1
IBMS	1	1	1	1	1	1	1	1	1	1

Uncertainty rating in a Combined Batch-and-Parameter based ordering system (Option III).

WH										
	Retailer			Wholesaler			Manufacturer			SC
E. I.	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	0	0	0	1	0	1	0	1	1	0
AOW	0	1	1	0	0	0	1	0	1	0
PT	0	1	1	0	1	1	1	1	1	1
IBMS	0	1	1	0	1	1	1	1	1	1
MF										
	Retailer			Wholesaler			Manufacturer			SC
E. I.	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	0	1	1	1	1	1	3	1	2	1
AOW	0	0	0	0	0	0	0	0	0	0
PT	0	1	1	0	0	0	1	1	1	1
IBMS	0	1	1	0	1	1	1	1	1	1
NT										
	Retailer			Wholesaler			Manufacturer			SC
E. I.	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	0	0	0	1	0	1	0	1	1	0
AOW	0	1	1	0	0	0	1	0	1	0
PT	0	1	1	0	1	1	0	1	1	1
IBMS	0	1	1	1	1	1	1	1	1	1

APPENDIX 6.2 UNCERTAINTY RATING UNDER INFORMATION INTEGRATION

Uncertainty rating in a Parameter based ordering system (Option I).

RW										
	Retailer			Wholesaler			Manufacturer			SC
	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	1	1	1	0	0	0	0	1	1	1
AOW	1	0	1	0	1	1	1	0	1	1
PT	1	0	1	0	1	1	0	0	0	0
IBMS	1	0	1	1	1	1	0	0	0	1
WM										
	Retailer			Wholesaler			Manufacturer			SC
	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	1	0	1	1	1	1	0	0	0	1
AOW	1	0	1	0	0	0	0	0	0	0
PT	1	0	1	0	0	0	0	1	1	0
IBMS	1	0	1	0	0	0	1	1	1	1
RWM										
	Retailer			Wholesaler			Manufacturer			SC
	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	1	1	1	0	1	1	1	0	1	1
AOW	1	0	1	1	0	1	1	0	1	1
PT	1	0	1	0	1	1	0	1	1	1
IBMS	1	0	1	1	1	1	0	1	1	1

Uncertainty rating in a Batch ordering system (Option II).

RW										
	Retailer			Wholesaler			Manufacturer			SC
	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	1	3	2	3	0	2	3	2	3	2
AOW	1	2	2	1	0	1	3	1	2	1
PT	0	1	1	1	1	1	3	1	2	1
IBMS	1	1	1	1	1	1	2	1	2	1
WM										
	Retailer			Wholesaler			Manufacturer			SC
	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	1	3	2	1	1	1	1	0	1	1
AOW	1	1	1	1	1	1	1	1	1	1
PT	1	1	1	1	1	1	1	1	1	1
IBMS	1	1	1	1	1	1	1	1	1	1
RWM										
	Retailer			Wholesaler			Manufacturer			SC
	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	1	3	2	3	1	2	1	1	1	2
AOW	1	2	2	2	0	1	0	1	1	1
PT	0	1	1	0	1	1	0	0	0	0
IBMS	1	1	1	1	1	1	0	0	0	1

Uncertainty rating in a Combined Batch-and-Parameter based ordering system (Option III).

RW										
	Retailer			Wholesaler			Manufacturer			SC
	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	1	0	1	0	1	1	1	0	1	1
AOW	0	0	0	0	0	0	1	0	1	0
PT	0	0	0	0	1	1	0	1	1	0
IBMS	0	1	1	1	1	1	1	1	1	1
WM										
	Retailer			Wholesaler			Manufacturer			SC
	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	1	1	1	1	0	1	1	0	1	1
AOW	1	0	1	1	0	1	1	0	1	1
PT	0	0	0	0	0	0	1	1	1	0
IBMS	0	0	0	0	1	1	1	1	1	1
RWM										
	Retailer			Wholesaler			Manufacturer			SC
	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	1	0	1	0	1	1	1	0	1	1
AOW	0	0	0	1	1	1	0	1	1	1
PT	0	0	0	0	1	1	1	1	1	1
IBMS	0	1	1	1	1	1	1	1	1	1

APPENDIX 6.3 UNCERTAINTY RATING UNDER INFORMATION INTEGRATION AND SUPPLY STRUCTURE INTERACTION

Uncertainty rating under WH structure and information integration interaction in a Parameter based ordering system (Option I).

4										
	Retailer			Wholesaler			Manufacturer			SC
	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	0	1	1	0	1	1	0	1	1	1
AOW	0	0	0	0	0	0	0	0	0	0
PT	1	0	1	1	1	1	0	0	0	1
IBMS	1	0	1	1	1	1	1	0	1	1
WM+WH										
	Retailer			Wholesaler			Manufacturer			SC
	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	1	0	1	0	0	0	1	0	1	0
AOW	1	0	1	0	0	0	1	1	1	1
PT	1	0	1	0	0	0	0	1	1	0
IBMS	1	0	1	1	0	1	1	0	1	1
RWM+WH										
	Retailer			Wholesaler			Manufacturer			SC
	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	0	1	1	0	0	0	1	0	1	0
AOW	0	0	0	0	0	0	1	1	1	0
PT	1	0	1	1	1	1	0	1	1	1
IBMS	1	1	1	1	1	1	1	1	1	1

Uncertainty rating under MF structure and information integration interaction in a Parameter based ordering system (Option I).

RW+MF										
	Retailer			Wholesaler			Manufacturer			SC
	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	0	1	1	0	0	0	0	1	1	0
AOW	0	0	0	0	0	0	0	0	0	0
PT	1	0	1	0	1	1	0	0	0	0
IBMS	1	1	1	1	1	1	1	1	1	1
WM+MF										
	Retailer			Wholesaler			Manufacturer			SC
	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	1	1	1	1	1	1	0	0	0	1
AOW	1	0	1	1	1	1	0	0	0	1
PT	1	1	1	1	1	1	1	1	1	1
IBMS	1	1	1	1	1	1	1	1	1	1
RWM+MF										
	Retailer			Wholesaler			Manufacturer			SC
	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	0	0	0	0	0	0	1	0	1	0
AOW	0	0	0	0	0	0	0	0	0	0
PT	1	0	1	0	1	1	1	1	1	1
IBMS	1	0	1	1	1	1	1	1	1	1

Uncertainty rating under NT structure and information integration interaction in a Parameter based ordering system (Option I).

RW+NT										
	Retailer			Wholesaler			Manufacturer			SC
	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	1	1	1	0	1	1	0	1	1	1
AOW	1	0	1	0	0	0	0	0	0	0
PT	1	0	1	1	1	1	0	0	0	1
IBMS	1	0	1	1	1	1	0	1	1	1
WM+NT										
	Retailer			Wholesaler			Manufacturer			SC
	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	1	0	1	0	0	0	0	0	0	0
AOW	1	0	1	0	0	0	0	0	0	0
PT	1	0	1	0	0	0	1	1	1	1
IBMS	1	0	1	1	0	1	1	1	1	1
RWM+NT										
	Retailer			Wholesaler			Manufacturer			SC
	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	1	1	1	0	0	0	1	0	1	1
AOW	1	0	1	0	0	0	0	0	0	0
PT	1	0	1	1	1	1	1	1	1	1
IBMS	1	0	1	1	1	1	1	1	1	1

Uncertainty rating under WH structure and information integration interaction in a Batch ordering system (Option II).

RW+WH										
	Retailer			Wholesaler			Manufacturer			SC
	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	0	3	2	3	0	2	1	0	1	1
AOW	0	1	1	1	0	1	1	1	1	1
PT	1	1	1	1	0	1	1	1	1	1
IBMS	1	1	1	1	1	1	1	1	1	1
WM+WH										
	Retailer			Wholesaler			Manufacturer			SC
	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	0	3	2	0	0	0	1	0	1	1
AOW	1	0	1	1	1	1	1	1	1	1
PT	1	1	1	1	1	1	1	1	1	1
IBMS	1	1	1	1	1	1	1	1	1	1
RWM+WH										
	Retailer			Wholesaler			Manufacturer			SC
	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	0	3	2	2	0	1	1	1	1	1
AOW	0	1	1	1	0	1	0	0	0	0
PT	1	1	1	1	0	1	1	1	1	1
IBMS	1	1	1	1	1	1	1	1	1	1

Uncertainty rating under MF structure and information integration interaction in a Batch ordering system (Option II).

RW+MF										
	Retailer			Wholesaler			Manufacturer			SC
	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	0	3	2	3	0	2	1	0	1	1
AOW	1	1	1	1	0	1	1	1	1	1
PT	1	1	1	0	1	1	1	1	1	1
IBMS	1	1	1	1	1	1	1	1	1	1
WM+MF										
	Retailer			Wholesaler			Manufacturer			SC
	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	0	3	2	0	0	0	1	1	1	1
AOW	1	1	1	1	1	1	1	1	1	1
PT	1	1	1	1	1	1	1	1	1	1
IBMS	1	1	1	1	1	1	1	1	1	1
RWM+MF										
	Retailer			Wholesaler			Manufacturer			SC
	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	0	3	2	3	0	2	0	0	0	1
AOW	1	1	1	1	0	1	0	0	0	1
PT	1	1	1	0	1	1	0	0	0	1
IBMS	1	1	1	1	1	1	1	1	1	1

Uncertainty rating under NT structure and information integration interaction in a Batch ordering system (Option II).

RW+NT										
	Retailer			Wholesaler			Manufacturer			SC
	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	0	3	2	3	0	2	3	1	2	2
AOW	1	1	1	1	0	1	3	1	2	1
PT	1	1	1	1	1	1	2	1	2	1
IBMS	1	1	1	1	1	1	2	1	2	1
WM+NT										
	Retailer			Wholesaler			Manufacturer			SC
	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	0	3	2	0	0	0	1	0	1	1
AOW	1	0	1	1	1	1	1	1	1	1
PT	1	1	1	1	1	1	1	1	1	1
IBMS	1	1	1	1	1	1	1	1	1	1
RWM+NT										
	Retailer			Wholesaler			Manufacturer			SC
	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	0	2	1	2	0	1	0	0	0	1
AOW	0	1	1	0	0	0	0	0	0	0
PT	1	1	1	1	1	1	1	1	1	1
IBMS	1	1	1	1	1	1	1	1	1	1

Uncertainty rating under WH structure and information integration interaction in a Combined Batch-and-Parameter based ordering system (Option III).

RW+WH										
	Retailer			Wholesaler			Manufacturer			SC
	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	0	0	0	0	0	0	0	0	0	0
AOW	0	0	0	0	1	1	1	0	1	0
PT	0	0	0	1	1	1	1	1	1	1
IBMS	1	1	1	1	1	1	2	1	2	1
WM+WH										
	Retailer			Wholesaler			Manufacturer			SC
	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	0	1	1	1	0	1	1	1	1	1
AOW	0	0	0	0	1	1	0	1	1	0
PT	0	1	1	0	1	1	0	0	0	0
IBMS	0	1	1	0	1	1	1	0	1	1
RWM+WH										
	Retailer			Wholesaler			Manufacturer			SC
	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	0	0	0	0	0	0	1	0	1	0
AOW	0	0	0	0	1	1	1	0	1	0
PT	0	0	0	1	1	1	0	1	1	1
IBMS	0	0	0	1	1	1	1	1	1	1

Uncertainty rating under MF structure and information integration interaction in a Combined Batch-and-Parameter based ordering system (Option III).

RW+MF										
	Retailer			Wholesaler			Manufacturer			SC
	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	0	0	0	0	0	0	0	0	0	0
AOW	0	0	0	0	1	1	1	1	1	1
PT	0	0	0	0	1	1	1	1	1	1
IBMS	1	1	1	1	1	1	1	1	1	1
WM+MF										
	Retailer			Wholesaler			Manufacturer			SC
	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	0	1	1	1	1	1	0	0	0	1
AOW	0	0	0	1	1	1	0	1	1	1
PT	0	1	1	1	1	1	1	1	1	1
IBMS	1	1	1	1	1	1	1	1	1	1
RWM+MF										
	Retailer			Wholesaler			Manufacturer			SC
	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	0	0	0	0	0	0	0	0	0	0
AOW	0	0	0	0	0	0	1	0	1	0
PT	0	0	0	1	1	1	1	1	1	1
IBMS	0	1	1	1	1	1	1	1	1	1

Uncertainty rating under NT structure and information integration interaction in a Combined Batch-and-Parameter based ordering system (Option III).

RW+NT										
	Retailer			Wholesaler			Manufacturer			SC
	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	0	0	0	0	0	0	0	0	0	0
AOW	0	0	0	0	1	1	0	0	0	0
PT	0	1	1	1	1	1	1	1	1	1
IBMS	0	1	1	1	1	1	1	1	1	1
WM+NT										
	Retailer			Wholesaler			Manufacturer			SC
	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	0	1	1	1	0	1	0	0	0	0
AOW	0	0	0	0	1	1	1	0	1	0
PT	0	1	1	0	1	1	0	1	1	1
IBMS	0	1	1	0	1	1	1	1	1	1
RWM+NT										
	Retailer			Wholesaler			Manufacturer			SC
	Hold	Backlog	R Total	Hold	Backlog	W Total	Hold	Backlog	M Total	Average
SFDD	0	0	0	0	0	0	1	0	1	0
AOW	0	0	0	0	1	1	0	0	0	0
PT	0	1	1	1	1	1	1	1	1	1
IBMS	0	1	1	1	1	1	1	1	1	1

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